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URBAN TRAFFIC CONTROL AND BUS PRIORITY SYSTEM

Vol. I. Design and Installation

November 1972
Final Report

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16. Abstract

This report presents a comprehensive review of the system design studies, analyses, traffic surveys, geometric surveys and tradeoff studies which were conducted in conjunction with the UTCS/BPS program, and which resulted in the selection of system components and parameters which comprise the first-generation UTCS/BPS centralized computer-based traffic control system. The results and conclusions presented herein highlight the advantages and disadvantages of the various components and parameters considered. The basis for selection for the UTCS/BPS is indicated in each case. This report thus serves as a guide in configuring and specifying a traffic control system when on-street design considerations affecting a specific application are taken into account.

This volume is one of a series of three comprising the complete final report on this R&D effort. The others are:

Report FHWA-RD-73-10. Vol. II. Operator's Manual.
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FOREWORD

An Urban Traffic Control and Bus Priority System has been implemented in the District of Columbia by the Sperry Systems Management Division under Federal Highway Administration Contract No. FH-11-7605, Advanced Control Technology in Urban Traffic Control Systems - Installation. The system includes on-street surveillance and control elements and a central office data processing facility. This report describes the system design studies, analyses, traffic surveys, geometric surveys and tradeoff studies which were conducted in conjunction with design and installation of the UTCS/BPS system.

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SECTION 1

INTRODUCTION, CONCLUSIONS, AND SUMMARY

1.1 INTRODUCTION

This volume constitutes the final report on the design and installation phase of the Urban Traffic Control System (UTCS) program. The design and installation were based on the requirements and specifications which were developed during a study phase conducted for the Federal Highway Adminstration (FHWA) by the Sperry Systems Management Division. The objective of this study was to design a digital computer-controlled traffic control system for the city of Washington, D.C. Prior to the completion of the UTCS study phase, requirements were defined and a study was initiated by the Urban Mass Transportation Administration (UMTA) for a Bus Priority System (BPS) which was to be implemented in conjunction with the basic UTCS. A separate study, with joint participation of the FHWA and UMTA, was then conducted by SSMD to develop the design and specifications for a Bus Priority System. As a result of this study, the design developed during the UTCS study phase was expanded so that an integrated system could be used to provide buses with preferential treatment in conjunction with the UTCS vehicular control strategies. The final installation phase thus consisted of an integrated UTCS/BPS computer-controlled traffic control system.

The purpose of the Urban Traffic Control System is to serve as a real-world research facility to test new and advanced traffic control strategies and programs, and to serve as a source of information for other cities which are contemplating the development and procurement of similar systems. The Bus Priority System will be used to determine experimentally whether bus delays can be decreased by giving buses preferential treatment at signalized intersections. The BPS configuration parallels that of the UTCS and, in addition, takes advantage of traffic parameters computed by UTCS, so that both systems can operate as a single integrated laboratory for testing advanced urban traffic control techniques and strategies including bus priority provisions.

Three generations of signal control strategy are presently planned for implementation and test in the UTCS area. Each generation represents more responsive, and necessarily more complex, processing of data. The present UTCS software constitutes the first generation. Advancement to the second and third generation will be achieved by additional software development phases.

1.1.1 FIRST GENERATION CONTROL SOFTWARE

This generation of control uses pre-stored timing patterns developed off-line and based on historical traffic data; the system is capable of storing up to 40 timing patterns. The pattern controlling the traffic system can be selected on the basis of time of day, by direct operator selection, or by matching the pattern best suited to traffic conditions. The mode of pattern selection is determined by the operator.

The pattern in effect is enhanced by critical intersection control (CIC), which is used to fine tune the system at intersections which saturate frequently by adjusting the allocation of green time (split) based on fluctuations in local traffic demand.

The first generation software also contains logic to enable a smooth transition between signal timing patterns with differing characteristics, in order not to disrupt traffic during the transition period. This transition routine evaluates the magnitude of the changes, determines the time required to effect a smooth transition, and then controls the signal parameters until the transition is complete. The same procedure is used for transition between computer control and standby.

Certain CIC intersections are instrumented for bus priority. The decision to grant additional green time to buses is a function of passenger volumes, vehicular queues in and around the intersection, and the time of arrival of a bus on the approach to the intersection. The computer logic which makes this decision is contained within the BPS algorithm. This algorithm analyzes the actual intersection conditions in real time and adjusts the signal splits in response to actual traffic demands.

1.1.2 SECOND GENERATION CONTROL SOFTWARE

In keeping with the role of UTCS as a laboratory for testing control strategies, a second generation of control software is being developed as an alternative to the stored patterns used by the first generation software. Second generation software contains an on-line optimization routine to determine the control parameters that will minimize the total delay and stops within the network under current traffic conditions. The optimization process is repeated at 15-minute intervals whenever traffic conditions have changed enough to justify the computation of a new set of control parameters.

Additional sophistication is also provided for the second generation critical intersection control. This routine will vary not only the signal split as in the case of the first generation software, but the relative green times between intersections (offsets) are also adjusted on a cycle-by-cycle basis to provide additional responsiveness to short-term fluctuations in traffic volumes.

Second generation software also has the capability for dynamically decomposing the network into subnetworks every 15 minutes on the basis of traffic conditions. The optimum timing patterns are then computed for individual subnetworks, and the subnetworks are interfaced to assure smooth traffic progression across the subnetwork boundaries.

A number of other routines are contained in the second generation software that are designed to improve traffic flow within the network, including an improved transition routine, a prediction capability, and software to estimate traffic conditions at intersections that are not instrumented with vehicle detectors.

1.1.3 THIRD GENERATION CONTROL SOFTWARE

The third generation software will provide a control algorithm that is responsive to changing traffic conditions on a cycle-by-cycle basis. To accomplish this goal, the control software will be designed to develop new traffic signal control parameters of cycle, offset, and split that vary between individual intersections and with each controller cycle.

This approach eliminates the need for transition routines between 15-minute timing patterns because the network is constantly in a state of transition, responding to changing traffic conditions. The use of variable cycle lengths at individual intersections simplifies the problem of different background cycle lengths that exists in second generation software as a result of the increased capability to adjust individual cycle lengths at the intersections within the subnetwork.

Thus, the principal improvements of third generation software over second are:

- Timing pattern, including cycle length, will be individually computed for each intersection while still maintaining overall network optimization
- Signal timing patterns will be optimized on a cycle-by-cycle basis, rather than the 15-minute interval of the second generation.

1.2 CONCLUSIONS

1.2.1 UTCS/BPS DESIGN AND INSTALLATION OBJECTIVES

The objectives of the Installation Phase of the UTCS/BPS have been met. The operability of the integrated system has been demonstrated, both under simulated and real traffic conditions. The system has been operational at the Washington, D.C. site throughout the integration phase, which began on May 1, 1972, and covered a period of approximately seven months. During this period, acceptance tests were conducted which entailed the testing of single- and multi-controller operation, MOE accuracy, the operability of the CIC algorithm, the operability of the Bus Priority System, and the operability of the pattern match operation in the traffic-responsive mode. In most cases the tests involved comparison and verification of field observations with corresponding system outputs at Central (See Appendix E). Successful pattern matching operation was demonstrated relative to stored patterns which were obtained off-line using SIGOP. The history data used in the SIGOP runs had been previously obtained from system outputs.

1.2.2 TRAFFIC-ORIENTED CENTRAL COMPLEX

The UTCS/BPS central complex is a highly developed human-engineered facility which is designed around an operator instead of a computer. In normal operation, the required computer-related skills are not intricate, so that the operator can devote his skills and effort to traffic functions. The CRT and map displays greatly enhance the surveillance of traffic situations, while the traffic control panel provides the means for rapid reaction to adjust the system to varying situations. The displays and control panel also permit rapid detection and isolation of detector and controller malfunctions, thereby enabling rapid repairs.

1.2.3 APPLICABILITY TO PLANNED URBAN TRAFFIC SYSTEMS

The UTCS first generation control strategy implementation is applicable to planned urban digital computer-controlled traffic systems. Utilization of the control concepts is a matter of completing the street installation and communication design to suit the application, and adapting the UTCS software to it. A FORTRAN translation of the

first generation software is currently being developed for the FHWA. The purpose of the translation is to make the UTCS more adaptable to various network and hardware configurations.

1.2.4 REQUIRED DESIGN PROCEDURES FOR UTCS TYPES OF TRAFFIC CONTROL SYSTEM

Extensive preliminary surveys and studies are required in order to arrive at a street installation design which will permit the maximum benefits to be derived, when used in conjunction with UTCS software and central design concepts. The basic steps include surveys and studies (using TOPICS reports where available) to:

- Evaluate existing controllers and controller subsystems, and determine whether they should be utilized or replaced
- Select the intersections to be controlled
- Determine the sectional breakdown (networks, arterials)
- Select intersections for CIC control
- Select number of detectors and their locations
- Select controller type
- Select detector type
- Select the back-up mode of operation
- Improve intersection geometric design and signalization
- Conduct geometric studies to determine parameters for generating patterns in conjunction with SIGOP
- Select the communication technique

- Determine whether it is more economical to lease or own communication cabling

- Prepare curbside installation drawings.

The street installation design affects certain aspects of the central design, such as computer configuration, communications design, map display design, and traffic control panel design.

Computer Configuration - The UTCS software must be capable of controlling the required number of intersections and detectors using an acceptable hardware configuration. This configuration can be specified initially for a smaller complex with a built-in growth capability. Planned traffic control complexes greatly exceeding 400 intersections (1000-2000 intersections) will require either multi-computer operation or the employment of more powerful computers than used in UTCS.

Communications - Central communications must be designed to accommodate the planned number of intersections. The design must be consistent with the street-to-central communications technique selected and must also provide the signal levels which properly interface with the Computer Interface Unit (CIU).

Computer Interface Unit - The CIU must be designed to accommodate the input/output signals for the total number of planned intersections, in addition to signals to the map display, traffic control panel, CRT display, and other computer peripheral equipments.

Map Display - The basic UTCS map display design, including the symbols, legends, lighting, and screens, can be utilized. However, the actual map, the number of displays, and the scaling must be determined. They will vary according to the size and breakdown of the controlled complex. The UTCS map electronics unit provides for the control of 1024 individual lamps, of which only 400 are presently used. The present design will probably be adequate for a planned complex of 400 intersections. Planned complexes greatly in excess of 400 intersections will require a redesign to expand the total number of control points to the desired level.

Traffic Control Panel - The basic UTCS control panel design is applicable. Minor changes are required, however, to remove BPS functions and experimental features of the UTCS.

1.3 SUMMARY

This report consists of seven major sections: Section 1, Introduction, Conclusions and Summary; Section 2, Functional Design Requirements; Section 3, Street Installation and Design; Section 4, Central System Design; Section 5, Bus Priority System Installation; Section 6, Verification of UTCS/BPS Operability; Section 7, Operation and Maintenance Staffing; and seven appendices. The seven appendices are: A, Glossary; B, Valid Control Panel Entries; C, Reports and Displays; D, UTCS Central Specification; E, UTCS Acceptance Test Plan; F, Sample UTCS/BPS Installation Reference Documents; and G, Sample Computer System Evaluation Work Sheet.

Sections 2, 3, and 4 each consist of two parts. The first part presents general information, including the types of studies, tradeoffs, and surveys which must be considered when specifying a computer-controlled traffic system. The second part of each section discusses the decisions, and the reasons for them, which led to the final UTCS system design configuration. Also included in the second part are descriptions of the final UTCS configuration, including field installation, communications, central installation, operation, and control.

In documenting the UTCS/BPS system, it was not always feasible or convenient to separate the description of the two elements. For example, the traffic control panel, CRT display, and map display include BPS as well as UTCS functions. Also, central communications combines UTCS and BPS signals. These components were, therefore, described as implemented in the integral UTCS/BPS system. Section 5, however, separately describes the considerations, studies, and tradeoffs which directly affected the BPS design, as well as the final Bus Priority System configuration.

Section 6 describes the operability of the UTCS/BPS in terms of the various milestones of the program including the simulation phase at the Sperry facility, the integration phase at Washington, D.C., and the acceptance testing phase at Washington, D.C. Section 7 describes the staffing recommendation which is based on experience gained during system integration.

SECTION 2

FUNCTIONAL DESIGN REQUIREMENTS

2.1 GENERAL

The following paragraphs list and describe the functional requirements of a computer-controlled traffic system.

2.1.1 CENTRAL SYSTEM FUNCTIONAL DESIGN

Salient central design characteristics required to achieve the desired functional operation are:

- The computer should be designed so that an inadvertent loss of power will not cause a loss of the program information.
- The traffic control program should be designed to permit the addition or deletion of controlled intersections without major revisions to the program.
- The traffic control program should be designed to permit the modification of the constants within the algorithms of the program as well as the modification of stored signal patterns.
- The traffic control program should be designed to provide, on demand, a statement of system status through the teleprinter, line printer, or CRT display by the insertion of a command.
- All commands for the modification or the manual control of the central computer program should be accomplished in direct English or in an easily learned code.
- The computer should be supplied with all programs required to operate the specified control system. The programs should be thoroughly tested and proven prior to submission for service.
- The central control equipment should be capable of interfacing with either an FDM or TDM communication system as dictated by street installation design considerations.

A. Traffic Control Panel Functional Design

The traffic control panel should permit control in four major functional areas:

- Street equipment control
- Status display control
- Auto-manual-alarm
- Map display control.

The control panel should be mounted on the operator console so as to be conveniently accessible by a system operator. Switches and indicators should be grouped by major functions to provide an indication of current operational status. Appropriate legends and color coding should be provided to indicate control functions in Traffic Engineering terminology. The Street Equipment Control functional area should provide as a minimum the following control functions:

- System operating mode (traffic responsive, time-of-day, manual and standby)
- Subsystem selection and mode of operation assignment
- Selection of any controller and:
  - assume control
  - relinquish control
  - acknowledge a failure report
  - report completion of repair
  - assign a special controller scheme, e.g., critical intersection
- Selection of any sensor and:
  - acknowledge a failure report
  - report completion of repair
  - remove sensor data from pattern selection process
  - restore sensor data to pattern selection process.

The Status Display Control functional area should provide as a minimum the following functions:

- Seleetion of output display on one or more of:
  - Line printer
  - CRT display
- Selection of status to be displayed.

The Auto-Manual-Alarm functional area should provide as a minimum the following functions:

- Manual release of controllers from computer control in the event of emergency
- Reset system to automatic mode after manual release
- Turn off the system alarm
- Indicate failure of computer to pass self test.

The Map Display Control functional area should provide as a minimum the following functions:

- Turn the map display board on or off
- Select the type of information to be displayed on the map
- Seleet the threshold level for the displayed parameter.

B. Map Display Functional Design

A map display should be provided to assist the traffic engineer in monitoring system performance. The display should include all roads within the controlled area containing signalized intersections. The map surface should be provided with a non-glare coating and should be shatterproof. Identifying names should be provided for each of the roads. Within the designated area, each controller which has been instrumented for computer control should be represented on the map by a red-green lamp and an arrow. The arrow should identify the street at the intersection which is designated as the A-phase and should indicate whether the A-phase street is one-way or two-way. If one-way the arrow should point in the direction of flow. Each link, or functional grouping, should be represented on the map by a colored lamp and an arrow. The arrow should identify the direction of traffic on the street. Legends should be provided on the map display identifying each mode of operation. Each legend should be capable of being illuminated during its corresponding operating mode. All map indications should be clearly visible and discernible by the operator from his normal operating station. The map should be capable of distinctively displaying at least the following types of data:

- Signal state (A-phase red and green)
- Flow data exceeding at least five selected thresholds for each of the following parameters:
  - Volume in vehicles per lane per hour
  - Occupancy in percent
  - Speed in miles per hour
  - Number of stops per cycle
  - Delay in seconds per vehicle
  - Queue in vehicles per cycle
- Controller status
  - Under computer control
  - Not under computer control
- Intersection status (e.g. CIC status)
- Controllers failed
- Sensors failed
- Lamp test
- Computer standby situation.

C. CRT Display Functional Design

An alphanumeric cathode ray tube (CRT) display should be provided at the operator's station. This device should permit an operator to view on demand the status reports selected by input requests initiated from either the system control panel or the computer keyboard.

The CRT display should have a non-glare viewing surface. The display format provided should permit a minimum of 900 characters per display page. Each display character should be readable from a distance of 7 feet in a normally lighted room.

2.1.2 CENTRAL PROCESSOR FUNCTIONAL REQUIREMENTS

Certain central processor functions are required for the proper operation of a traffic control system.

The computer is required to direct the operation of all the local intersection controllers in the system. It should operate on traffic flow data as supplied to it by the system sensors. The computer should determine the correct cycle length, offset and split to be used by the local controllers within the total system, subsystem (section) or in isolated operation. This information will be transmitted in the appropriate form to command either dial type, pretimed (fixed time) controllers or vehicle actuated controllers. The resolution of interval advance or change pulses should be at least one second or less.

Control function computations should be based on non-ambiguous traffic parameters. These should include, as a minimum, traffic volumes and percent of time of lane occupancy or density. The computer should be capable of operating, as a minimum, the maximum contemplated number of local controllers. It should also be capable of operating, as a minimum, the maximum number of subsystems (sections) of signalized intersections determined by preliminary geometric and traffic surveys. The programming should provide the subsystems the capability of operating individually, jointly, or in combinations based upon traffic demand and/or operator command.

A. Sensor Data Requirements

A separate input to the computer should be provided for each sensor. The computer should be capable of receiving input information, as a minimum, from the maximum number of expected sensors and local controllers, as determined from preliminary surveys. Sensor data inputs to the computer should be usable in the various computations as required by the stored programs and as selected by controls in the system control panel or through keyboard insertion into the program. The computer should detect and automatically remove the effect of a sensor that has failed. A sensor should be considered to have failed if its output has not changed state for a preselected time period or if it does not meet a reasonableness check of its data. Sensor failure should be an alarm condition and should be recorded as a failure.

The data from each sensor should be capable of being weighted. Each sensor should be sampled at a rate consistent with system accuracy requirements for speed and occupancy computations. The root mean square pulse length error due to sampling can be shown to be equal to $T/\sqrt{6}$ where T is the detector pulse sampling period (refer to Appendix D of Reference 3B). Speed and occupancy are determined in terms of vehicle presence or measured pulse width. The accuracy of these quantities is therefore directly affected by the sampling period. UTCS samples loop detector actuations at a rate of 32 times per second.

B. Signal Pattern Requirements

Vehicular flow control should be effected by imposing patterns of signal indications on the street network. These patterns should contain, implicitly or explicitly, the cycle length, split and offset for each controller in the system.

Signal patterns should be stored for each subsystem (section). Patterns should be selected in response to the subsystem traffic flow as indicated by sensor data processed by the system computer. They should be synchronized with respect to a subsystem (section) background cycle.

Stored pattern data should be generated off-line by techniques that optimize a function of vehicular flow (e.g. trip time or delay). The traffic engineer should provide the initial pattern data and identification information. Stored patterns should be improved and expanded when the system is on line, using system volume and occupancy outputs. The appropriate clearance intervals should be reflected in all patterns applicable to a controller. The pattern actually utilizied for each subsystem (section) should be recorded with the time it was initiated, each time that a change is made.

The computer should be capable of simultaneously changing the signal patterns for all subsystems (sections) that require changing. Provision should be made to minimize the effect of pattern change on system operation by controlling the offset change per cycle, the A-phase green per cycle, and the number of cycles for accomplishing the total change. Provision should be made to allow the introduction of other information such as time-of-day or special events into the process of pattern selection.

C. Pattern Selection

Stored patterns should be selected on-line on a subsystem (section) basis. Each pattern should be identified by representation of the flow conditions (e.g. lane volume and occupancy) under which the pattern is to be put into effect. Patterns should be selected from a comparison of current subsystem flow data with the ensemble of flow representation.

D. Standby Operation

Provisions should be made for picking up controllers from standby subsystem by subsystem. The computer should be capable of picking up control of any subsystem or any combination of subsystems at any one time in response to operator input.

Provision should be made for placing a subsystem, or a part thereof, in the standby mode when so instructed by the operator.

The computer should provide for receiving and checking the A-phase green return from each controller. Provisions should be made to place any controller into standby, if the A-phase green return differs by a specified amount determined by the program from the corresponding computer-derived interval. An attempt should be made to resynchronize the controller before it is dropped.

The computer should provide a signal for synchronizing the standby operation of the controllers. The synchronizing signal should be transmitted each time a subsystem is picked up from standby or released from computer control.

The computer should provide the means for outputting appropriate Measure of Effectiveness parameters (e.g. volume, speed and occupancy) during standby operation.

E. Fixed-Time Controllers

The computer should be capable of providing each controller with interval advance signals. Each signal should correspond to one interval of the controller cycle.

All fixed time controllers should be timed by the signal patterns in effect for the subsystem in which the controllers are located. A controller that cannot be timed from the computer should revert to standby operation.

F. Critical Intersection Controllers

All critical intersection controllers should operate under the cycle lengths and offsets appropriate to the patterns imposed on the subsystem in which they are located. The splits of these controllers, however, should be adjusted as a function of data derived from sensors located in their vicinity.

The vehicle green time should be allocated to the phases of the controller in proportion to the demand sensed at the approaches to the intersection. Actuated intervals and phase-skipping may be accommodated by locally sited hardware.

G. Actuated Controllers

Actuated controllers may be implemented by local hardware. The computer should provide yield and force-off signals for actuated controllers. The local controller timing should be set to appropriate settings to allow for computer control. Vehicle actuated phases should have a maximum timing set beyond the maximum timing expected from the computer for that phase.

For vehicle-actuated and pedestrian-actuated controllers, the split information should appear at the local controller as a yield pulse to permit it to leave the coordinated arterial phase and as a force-off voltage which should command the termination of the actuated phase. Termination of the actuated phase, or phases, may be accomplished locally without force-off voltages, when permitted by dial setting adjustment within the controller. Each actuated phase should be provided with a separate force-off voltage. Adequate logic should be provided to assure protection against one actuated phase being forced off by the force-off voltage of another phase.

It should be possible for the operator to transmit a manual command from the computer to the intersection controllers that should cause the controllers to cycle through all phases and remain in each phase until the force-off for that phase occurs. It should be possible for the operator to direct this command to a single controller or to a group of controllers, up to a maximum of one subsystem. This command would be repeated in each cycle until instructed to cease.

Timing of pedestrian intervals or separate pedestrian phases should be done by local intersection hardware and not be done by the computer.

H. Alarms

Provision should be made to display and to sound a continuous audible alarm for situations that may require system or equipment shutdowns. These situations should include:

- Parity errors within the central processor
- Computational errors in the control program
- Failure of reasonableness checks
- Loss of a minimum complement of peripheral equipment
- Failure of curbside equipments

- Sensor data check
- Communications channel check.

I. Traffic Control Panel/Operator/Computer Interface

The traffic control panel should provide the operator with the means to perform traffic system functions in a straightforward manner, without knowledge of codes as would be required in a keyboard operation. The traffic control panel/operator/computer interface should provide the following operational functions as a minimum.

Any manual intervention should be recorded as to type (e.g. manual pattern change) and the time it occurs.

Provision should be made for system shutdown which allows the operator to shut down the system at any time. This function should be effected either through the computer, in which case the system should be returned to standby smoothly, or by means of an emergency release in response to an alarm condition.

The operator should be provided with the means to effect control over the following functions from the traffic control panel:

- Pattern selection
- Intersection control
- Standby transitions
- Sensor control
- Display control
- Failure acknowledge and repair.

J. Reporting Programs

Provision should be made to display current operating data on demand. These logs should consist of selectable pages containing the following information for outputting as hard copy and CRT display. The following three reports should be provided as a minimum:

- System Status - This report should tabulate for each section the following information:

- Section number
- Operating mode
- Time of last mode change
- Pattern number
- Sensor and controller failure totals
- Local intersection control summary (e.g. CIC and BPS)

- Failure Status - This report should tabulate, on a system basis, the following information for equipments that have failed:
  - Equipment type (e.g. controller)
  - Equipment number
  - Date of failure
  - Time of failure
  - Action taken

- Intersection Status - This report should contain the intersection number and location in the report heading. The following information should be presented:
  - The section number in which the intersection has been located
  - Local control status (e.g. CIC and BPS operation)
  - The controller status (on-line, standby, etc.)
  - Number of phases at the intersection
  - Number and duration of intervals in a complete cycle
  - Pattern data in effect
  - Cycle length in effect
  - Offset - the displacement of A-green from background cycle reference point, in seconds
  - A-phase green in seconds
  - B-phase green in seconds
  - C-phase green in seconds

- Minimum permissible phase green times
- Flow - identification of phase and flow direction (e.g. A-northbound, B-westbound)
- Sensor number - the identification number of the sensors (or links) measuring flow on each phase.

The following flow parameters should be displayed, as a minimum, for each phase:

- Volume in vehicles/hour
- Speed in miles per hour
- Occupancy in percent.

Provision should be made to print out on demand a time sequential system log. This log should consist of the following information, with events listed sequentially by time:

- All changes in subsystems or equipment status effected either manually or automatically, including the level of the change (e.g. system, section, controller, detector, communications, etc.) and the type of change (e.g. on-line, standby, traffic responsive, offset, split, etc.)
- The latest copies of the display reports described above (System Status, Failure Status, and Intersection Status) as a minimum.
- All measured and calculated traffic flow parameters used as a means of evaluating the system's performance, including as a minimum for all * instrumented lanes or links:
  - Volume in vehicles per lane per hour
  - Occupancy in percent
  - Average speed in miles per hour
  - Number of stops per cycle
  - Delay in seconds per vehicle.

---

*Parameters for out-of-tolerance (differing significantly from normal history values) links only need be printed out, if a log tape is made concurrently which includes all links for each period during system operation.

The time sequential system log should be perused and reorganized or summarized in a non-real-time mode in a system summary log. The data for this operation should be derived from the time sequential system log stored in the mass storage. The reorganized log should be printed out in hard copy. This system log summary should consist of an end-of-the-day summary of the following data for each instrumented lane or link:

- Total volume in vehicles
- Average occupancy in percent
- Average speed in miles per hour
- Total number of stops in vehicles
- Total delay in hours.

Similar quantities accumulated or averaged over each subsystem (or section) should also be stored and printed out in the end-of-day report.

Provision should be made to periodically output a log tape of the reports included in the periodic printouts described above. The tape should include parameters for all links since it will be used in conjunction with off-line programs for evaluating system performance and for generating traffic patterns from system data.

K. Subsystem Synchronization

Provision should be made to synchronize system controller background cycles with the background cycles of adjacent controllers which are not in the control complex, during system start-up.

For system controllers which are not coordinated by a master dial during local dial operation, the computer should transmit synch signals to the controllers to maintain the synchronization of the local dials while under computer control.

2.2 UTCS/BPS FUNCTIONAL DESIGN SUMMARY

The UTCS/BPS system interfaces with the field controllers so that the original local-dial system remains intact and provides a back-up (Standby mode) for the computer-controlled system. Control of traffic signal timing sequences is provided by developing a library of area "control patterns" for each of several sections (group of intersections).

The resulting cycle, split, and offset for each traffic signal are synchronized in the computer so that the "advance" pulses transmitted to the controller cam mechanism provide the desired timing sequences. The selection of the control pattern to be used may be based on time of day, automatic response to traffic conditions, or operator choice.

Critical intersections (those which saturate frequently) may have their split adjusted to be directly proportional to the green demand times computed for their associated links. This split control overrides the area control pattern in effect for that intersection. BPS intersections (those which are instrumented for bus priority operation) can also effect an override of the area control pattern by extending the green time on either the A or B phase.

Semi-actuated intersections continue to operate in their local control mode, with the exception that the computer synchronizes their response to the side-street traffic with respect to the computer-timed cycle length, thus maintaining the proper offset relationship with other controllers within the section.

The integrated UTCS/BPS system provides the operator with a large measure of flexibility and ease in controlling various system functions. Built-in error detection automatically indicates an "error" or "wait" condition when an invalid operator selection is made. A broad selection of comprehensive reports and displays for analyzing system performance, traffic surveillance, system status, and failure status is available. Hard copies of various reports and tapes are provided at 15-minute intervals and at the end of day for analyzing system performance as well as for the off-line generation of control patterns.

The system provides for the continuous and automatic testing of key system components, including controllers, vehicle detectors and communications, and bus detector and communications. In addition, the system automatically reacts to a detected failure to minimize the impact on system operation and performance. For example, if a vehicle detector fails, the computation of the MOE's for the associated link is automatically inhibited. A malfunction indication (audible and visible) on the traffic system control panel alerts the

operator to the failure so that he may react immediately to acknowledge and isolate the fault, thereby effecting a prompt correction.

2.2.1 CONTROL STRATEGIES

A. Area Control

The function of area control is to establish a desired set of control parameters (cycle, split, and offset) for all the controllers in a section. A section consists of a group of local controllers which will always be operating in the same control mode, and which will always switch from one selection of control parameters (pattern) to another, at the same time. Control parameters are selected for an entire section of controllers in order to maintain a workable interface between intersections within a section, and to maintain realistic vehicle progression speeds along the primary arteries within the section by an appropriate selection of controller offset data.

B. Intersection Control

The function of intersection control is to establish the desired set of control parameters (cycle, split, and offset) for one or more specific controllers (or intersections) within a section. Intersection control functions in conjunction with and supplements the area control operation. Supplementary control can be affected at an intersection by:

- Operating as CIC
- Operating as BPS
- Operator selection of an offset or split change.

(1) Critical Intersection Control (CIC)

Intersections which saturate frequently are instrumented for queue determination on the links associated with the two major phases. Splits for these intersections are then changed on a once-per-cycle basis as a function of the computed values of queues and volumes on these links. This critical intersection control is superimposed on the area control which is in effect. At those intersections instrumented and designated as critical intersections, the split value selected by the area control algorithm will thus be overridden as a function of the existing local demand.

The operator may initiate or terminate critical intersection control via the control panel at any time. It should be noted that an intersection could be designated and operating as a CIC without affecting a change in split on any given cycle. The area control imposed split is modified only if the green demand time, which is based on the normally expected queue from history and the current volume on any link, exceeds a threshold value. The split is then apportioned in accordance with the computed green demand time for all multi-detector links at the intersection. Conversely, the split will revert to the area control value if the green demands on all links fall below a lower threshold value. Details of the UTCS CIC algorithm are contained in the appendix of Reference 4A.

An intersection is automatically inhibited from CIC control, although it has been designated by the operator, for the following reasons:

- A detector (or associated communications) on any of the associated multi-detector links fails. It should be noted that the intersection will not be placed in CIC operation after the detector is repaired and on-line until at least one cycle of queue and volume data is obtained.
- The controller is in Standby.
- The local controller timing and phasing configuration makes CIC operation unfeasible. The intersections affected are inhibited on a TOD basis.
- The controller is in transition. (CIC operation will actually be inhibited for one additional cycle following the last transition cycle.)
- An operator offset change is in effect.
- A bus priority extension has been granted which carries over to the next cycle. This situation may come about if a bus priority extension is granted on the B-phase.

(2) Bus Priority System (BPS) Control

Bus extensions are granted at intersections instrumented for BPS operation on a cycle-to-cycle basis. The extensions affect the split, and can affect the offset and cycle length depending on which phase the extension is granted. An extension of the A-phase is followed by an equivalent shortening of the B-phase, which does not affect the A-phase offset or the cycle length. However, an extension of the B-phase lengthens the working cycle,

delays the A-phase offset by the length of the extension, and is followed by a cycle which is shortended by the amount of the extension.

Bus extensions are granted to eligible buses only (that is, a Thru bus which arrives at the upstream detector one second before the start of amber, or a Stop bus which arrives at the upstream detector one second plus its average loading time before the start of amber where the loading time is a function of time of day and bus zone. During normal operation, an extension is granted based on a comparison of the gain in passenger-minutes on one phase with that on the opposing phase. All eligible buses in the bus zones, as well as vehicles, are taken into account. An extension is granted to a phase only if it has a possible net gain which exceeds a pre-established threshold. A threshold of 2 passenger-minutes is used in the BPS. An intersection could thus be designated for BPS operation and operate as such without granting an extension on any given cycle. In the Preempt mode, the passenger gain threshold criterion is bypassed. Extensions are then granted whenever eligible buses enter a bus zone. Extensions on opposing phases are granted in turn. Details of the BPS algorithm are contained in paragraph 5.5.2 of this report.

An intersection is automatically inhibited for BPS control, although it has been so designated by the operator, for the following reasons:

- The intersection is inhibited for CIC operation.
- The intersection is operating as a CIC and is in the process of granting a split change. Under these conditions the granting of a bus extension might be in conflict with the split changes necessitated by the green demand.
- A bus detector (or associated communications) on any of the bus zones at the intersection fails.

The granting of bus extensions on successive cycles is permissible on the A-phase, provided the sequence is not interrupted by the granting of an extension on the B-phase. Bus extensions are inhibited on the cycle following a B-phase extension. This is required in order to preserve the cycle length and the A-phase offset relationships on subsequent cycles.

(3) Operator Split Change

An operator split change can be effected via the control panel by a selection of the desired A-phase green, in seconds, for the intersection for which the change is desired.

This change is implemented at the beginning of the next cycle. A split change is not permitted (indicated by the "error" light) if:

- The controller is not under computer control.
- The intersection has already been selected and is operating as a CIC.

In addition, the computer will not accept (indicated by the "wait" light) a split change if:

- The associated controller is in transition.
- A new pattern is being read in from the RAD.

The computer automatically rejects (indicated by the "error" light) a split change, if either the minimum permissible A-phase or B-phase greens would be violated as a result of the desired change. The CRT Intersection Status page can be used to determine the limits imposed on the variable A-phase and B-phase intervals. The page lists the minimum A-phase green for the intersection as well as the values of all the controller intervals.

(4) Operator Offset Change

An operator offset change can be effected via the control panel. This is implemented by a selection of the desired offset, in seconds, for the intersection for which the change is desired. The offset change is not permitted, indicated by the "error" light, if the controller is not under computer control. In addition, the computer will not accept (indicated by the "wait" light) an offset change if the associated controller is in transition or a new pattern is being read in from the RAD. The offset change is automatically rejected (indicated by the "error" light) if the operator offset value exceeds the operating cycle length.

The offset change is implemented incrementally on a cycle-to-cycle basis. The computer will either increase the offset by 6 seconds or decrease it by 3 seconds each cycle until the desired offset is obtained. The quickest path is automatically chosen by the computer.

The CRT Intersection Status page can be used to advantage in observing the cyclical changes in the offset. The actual working offset and the entry offset are listed for the intersection. When an operator offset change is entered, the entry offset will continue

to indicate the value for the area pattern. The actual offset will, however, increase or decrease each cycle until the actual offset is equal to the new offset value desired by the operator.

C. Mode Control

The UTCS/BPS traffic system operates in four modes of area control:

- Standby
- Time of Day (TOD)
- Traffic Responsive
- Manual Pattern.

(1) Standby Mode

In the Standby mode, the controllers are released from computer to local dial control. The UTCS computer is on line during standby operation, however, and limited system functions are available. For example, the volume, speed, and occupancy parameters are displayed and recorded for all links. These data can be utilized for generating patterns. Furthermore, the traffic system control panel can operate in conjunction with the UTCS computer for selecting CRT and map displays, for updating failure status tables, and for implementing subsequent mode changes. Vehicle detector and communications failure detection continue to function during Standby operation. All CIC and BPS operation is, however, inhibited in the Standby mode.

The Standby mode is selectable by the operator on a system (all sections), on an individual section or on a single controller basis. The request is immediately put into effect by the computer which effects a smooth transformation to local control.

If the operating mode of a section or sections was Standby at the last system shutdown, the operating mode of the section or sections will be Standby when the traffic system is again placed on line. Operation will continue as such until a mode change request is made.

(2) Time of Day (TOD) Mode

In the TOD mode, control patterns are automatically selected on a time-of-day and day-of-week basis. The change of control parameters is accommodated with a time resolution of 15 minutes for each section in the system. This resolution accommodates all switching times in the present District system, including the switching times required for the changing of parameters due to lane or street directional flow changes.

The initial library of TOD patterns constitutes a duplication of the District's 3-dial system, that is, Basic (off peak), AM Peak and PM Peak, and serves as a back-up mode for the existing time-of-day control. The library will be expanded to include anticipated additional switching times and patterns. This will be accomplished when volume and occupancy history data become available. Patterns for intermediate hours may provide smoother transitions from the basic pattern to a peak pattern and vice versa.

The TOD mode is selectable by the operator on a system (all sections) or on an individual section basis. The request is immediately put into effect by the computer, which effects a smooth transformation using transition cycles.

If the operating mode of a section or sections at the last system shutdown was TOD, Traffic Responsive, or Manual Pattern, the traffic system will be brought on-line in the TOD mode. This is done for the following reasons:

- To allow the system to gather data required to implement the Traffic Responsive mode
- To prevent a manually chosen pattern which is not appropriate for this Time of Day from being imposed.

Sections which were in TOD or Manual Pattern will continue to operate in TOD until a mode change is requested by the operator. Sections which were in Traffic Responsive at the last shutdown will revert to the Traffic Responsive mode after a full 15 minutes of volume and occupancy data are obtained.

(3) Traffic Responsive Mode

The Traffic Responsive mode is the primary operating mode of the UTCS/BPS Traffic System. In this mode, the computer selects the "best" available pattern for each section as a function of the latest smoothed traffic data, but is constrained to a maximum

of one change every 15 minutes. The times for these changes, if they are required, are on the hour and each quarter-hour thereafter.

The Traffic Responsive mode provides adaptive traffic-responsive area control wherein existing control patterns may be updated or new patterns may be introduced where required. New control patterns are generated off-line.

The selection of control parameters for a section of controllers is performed by locating the data history which is "closest" to the current smoothed data. The comparison criterion used is "volume plus weighted occupancy" (volume + weighting factor x occupancy) which yields a realistic indication of existing traffic demand.

Each history for a section of controllers is uniquely related to a set of control parameters (control patterns). The control pattern which is related to the best data-history match is selected from the available control patterns. However, if the control pattern being imposed is one of these available patterns and its match is not significantly worse than the best which was computed, no change is initiated.

The Traffic Responsive mode is selectable by the operator on a system (all sections) or on an individual section basis. The request is immediately recorded by the computer and Traffic Responsive operation is in effect. The initial Traffic Responsive pattern selection will be made on the next 15-minute mark.

(4) Manual Pattern Mode

The Manual Pattern mode is used primarily for handling unusual traffic conditions not provided for when operating under TOD or Traffic Responsive control. This control mode may be required during the checkout of traffic-responsive control patterns, or to provide rapid response, if the approximate time of the occurrence of an unusual traffic condition is known (i.e., ball game, concert or parade).

The Manual Patterr mode is selectable on an individual section basis only. The request is immediately put into effect by the computer, which effects a smooth transformation using transition cycles. Once the Manual Pattern mode has been put into effect, the section will continue to operate in this mode until the operator makes another mode change, or until the pattern selected is no longer valid for the time of day. If the Manual Pattern mode was in effect at the last shutdown, the mode will be overridden when the traffic system is placed on line again. The mode will be automatically changed to TOD.

2.2.2 UTCS MOE PARAMETERS

Seven MOE parameters are used in UTCS. They are:

- Delay
- Occupancy
- Queue
- Speed
- Stops
- Travel Time
- Volume.

The MOE's are defined in Appendix A together with a summary indicating the system reports in which they are presented.

2.2.3 UTCS TRAFFIC ALGORITHMS

A. Smoothed Quantities

Whenever smoothed MOE values are required, the following equation is applied:

$$Qu(I) = Qu(I-1) + K * [QM - Qu(I-1)]$$

where

Qu(I) = Ith value of the quantity
QM = Measured value of the quantity
K = Smoothing filter constant (varies from 0 to 1)

B. Volume

The volume, V, in vehicles per hour (vph) on each link is determined by:

$$V = \frac{1}{jT} \sum_{k=1}^{i} n(k)$$

where

j = Number of detectors in link

n(k) = Number of vehicles counted by detector, k, over time T (in hours)

The volume, VO (= number of cars leaving the link during link green), is given by:

VO = ZDO + CC1

where ZDO = Number of cars between stop bar and first (furthest downstream) detector at end of green

CC1 = Number of cars crossing first detector during green

The determination of ZDO is discussed below under "Queues and Stops". The value of VO used in the CIC routine is the smoothed value.

C. Occupancy

The percent occupancy, Occ, is derived as follows:

$$Occ = \frac{100}{jT_s LL} \sum_{k=1}^{j} \sum_{i=1}^{n(k)} (TT(i,k) - TD)$$

where

j = Number of detectors on link

T_s = Total time in seconds over which summation takes place

LL = Correction factor for finite loop length

$= \frac{LBAR + EL}{EL}$

LBAR = Average car length

EL = Effective loop length

TT (i,k) = Measured presence time in seconds of ith vehicle over detector, k

TD = Detector bias (drop-in plus fall out time) in seconds

n(k) = Number of vehicles counted by detector, k

D. Speed

The equation for determining the average speed, S, in miles per hour is (assuming that each vehicle has a length of LBAR feet):

$$S = \frac{KV1*LL}{n(k)} \sum_{k=1}^{j} \sum_{i=1}^{n(k)} \frac{1}{(TT(i,K) - TD)}$$

where

KV1 = Constant for converting sec^{-1} to miles per hour. (This constant contains LBAR)

LL = Correction factor for finite loop length

n(k) = number of cars counted by detector, k

j = Number of detectors on link

TT(i,k) = Measured presence time in seconds of ith vehicle over detector k

TD = Detector bias in seconds

E. Queues and Stops

The determination of queues and stops depends on the continuous measurement of the number of cars in each zone in a multidetector link, where:

Zone 0 is the portion of the link between the furthest downstream detector (detector 1) and the stop bar,

Zone 1 is the portion of the link between detector 1 and detector 2 (the next upstream detector), and

Zone 2 is the portion between detectors 2 and 3, if there is a third detector.

Whenever the traffic is flowing freely, the zone counts are maintained by a simple in and out count of the vehicles, with the restrictions that the number in each zone can never fall below zero and can never exceed the capacity of the zone.

Whenever a car entering a zone expects to stop in a zone, its speed over the upstream detector will depend on where the driver expects to stop, i.e. the distance expressed in car lengths. Thus, the duration of the presence signal over the detector can be related to the number of cars the driver sees within the zone he is entering:

Q = QCAP - D (TTC)

where

Q = Number of cars in zone observed by driver, which are expected to stop in the zone

QCAP = Capacity of zone in terms of car lengths

D(TTC)= Expected stopping distance in car lengths as a function of corrected detector pulse width, TCC
(= TT - TD, where TT = observed pulse width and TD = detector bias)

Defining N2 = Q1 - QCAP

where Q1 = Capacity of Zone 1, car lengths

the equation can be rewritten as

$$Q = Q1 = D(TTC) - N2$$
$$= QM(TTC) - N2$$

where $QM(TTC) = Q1 - D(TTC)$

The function (QMTTC) is obtained by actual observations. Figures 2-1, 2-2 and 2-3 were plotted on the basis of aerial photographs of traffic flow in the UTCS area. The three different plots are due to three different free flow speeds, which in turn can be related to the lengths of a link.

Any car in Zone 2 which can still find room in Zone 1 will not stop in Zone 2. The number of such cars, TP, is given by

$$TP = Q1 - ZD1$$

where ZD1 = Cars in Zone 1.

Thus the number of cars observed in Zone 2 DM, is

$$DM = QM + TP.$$

In the case of Zone 1, DM = QM.

Since DM can only be regarded as an estimated number, the actual car count, ZD, in a zone is taken to be

$$ZD(I+1) = ZD(I) + KN * [DM - ZD(I)] + 1$$

where

KN = Zone count smoothing filter constant.

The factor 1 is due to the fact that the car crossing the upstream detector must be added to the number of cars in the zone.

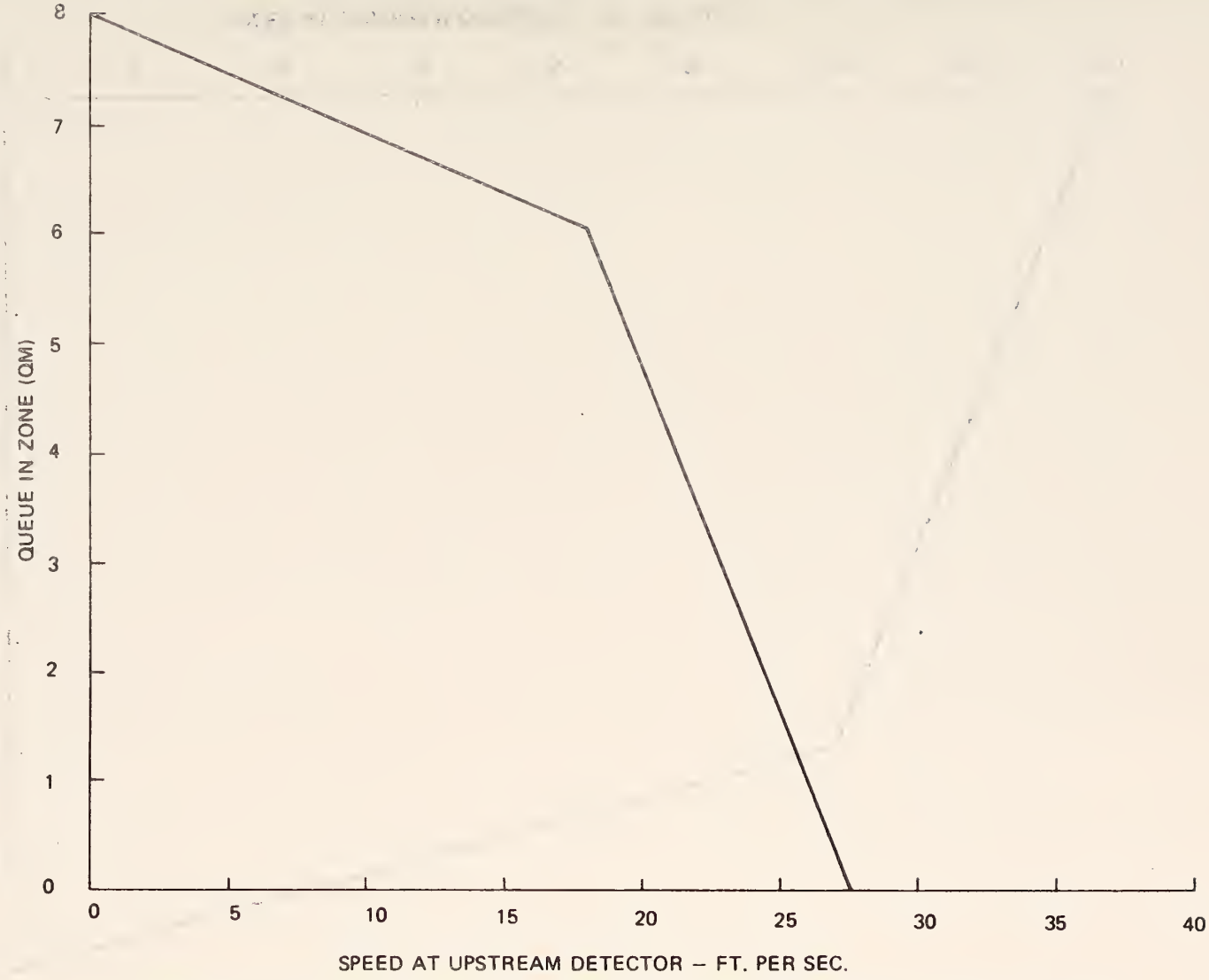


Figure 2-1. Observed Queue vs. Speed Over Detector - Block < 400 Feet Long

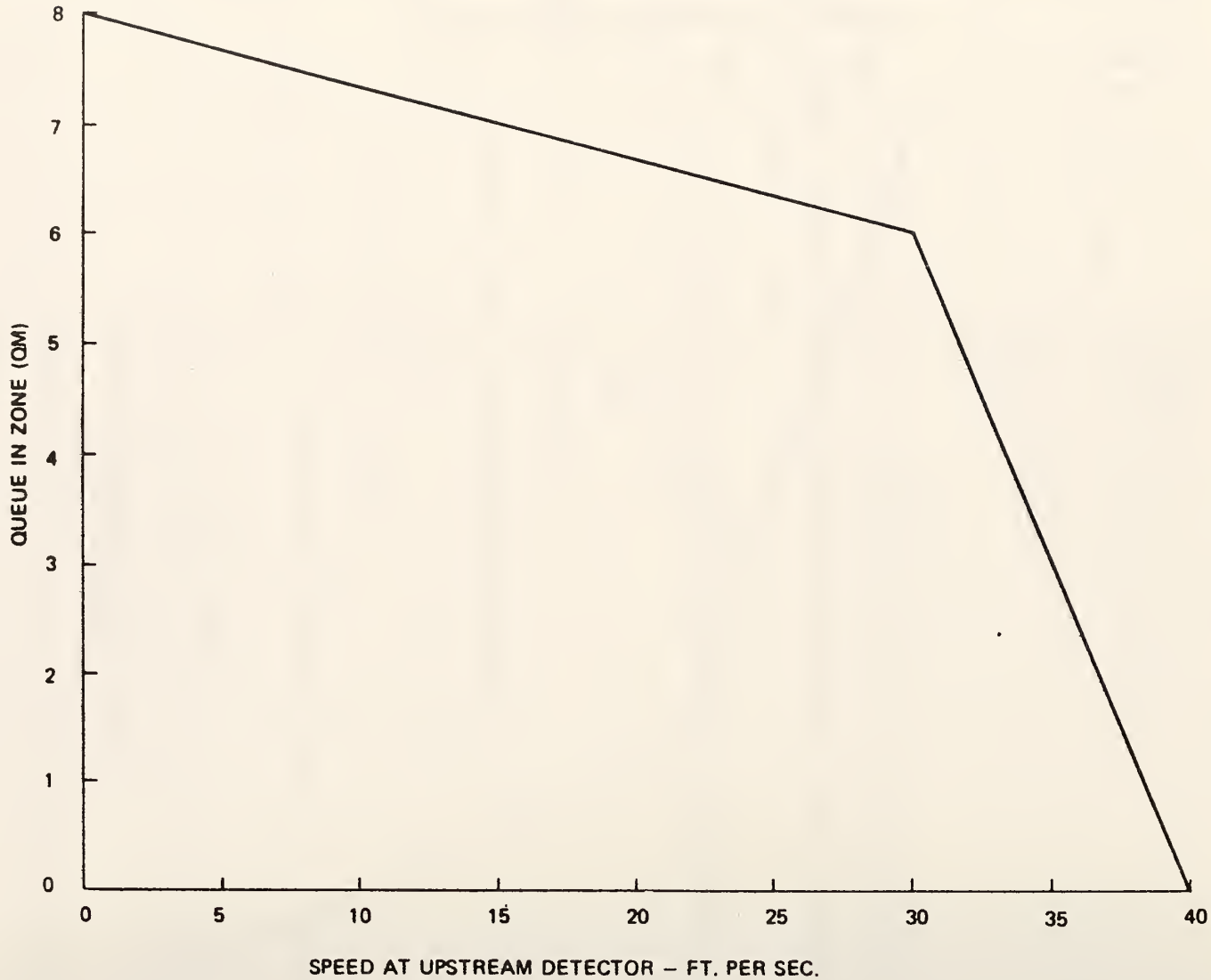


Figure 2-2. Observed Queue vs. Speed Over Detector - Block > 500 Feet Long

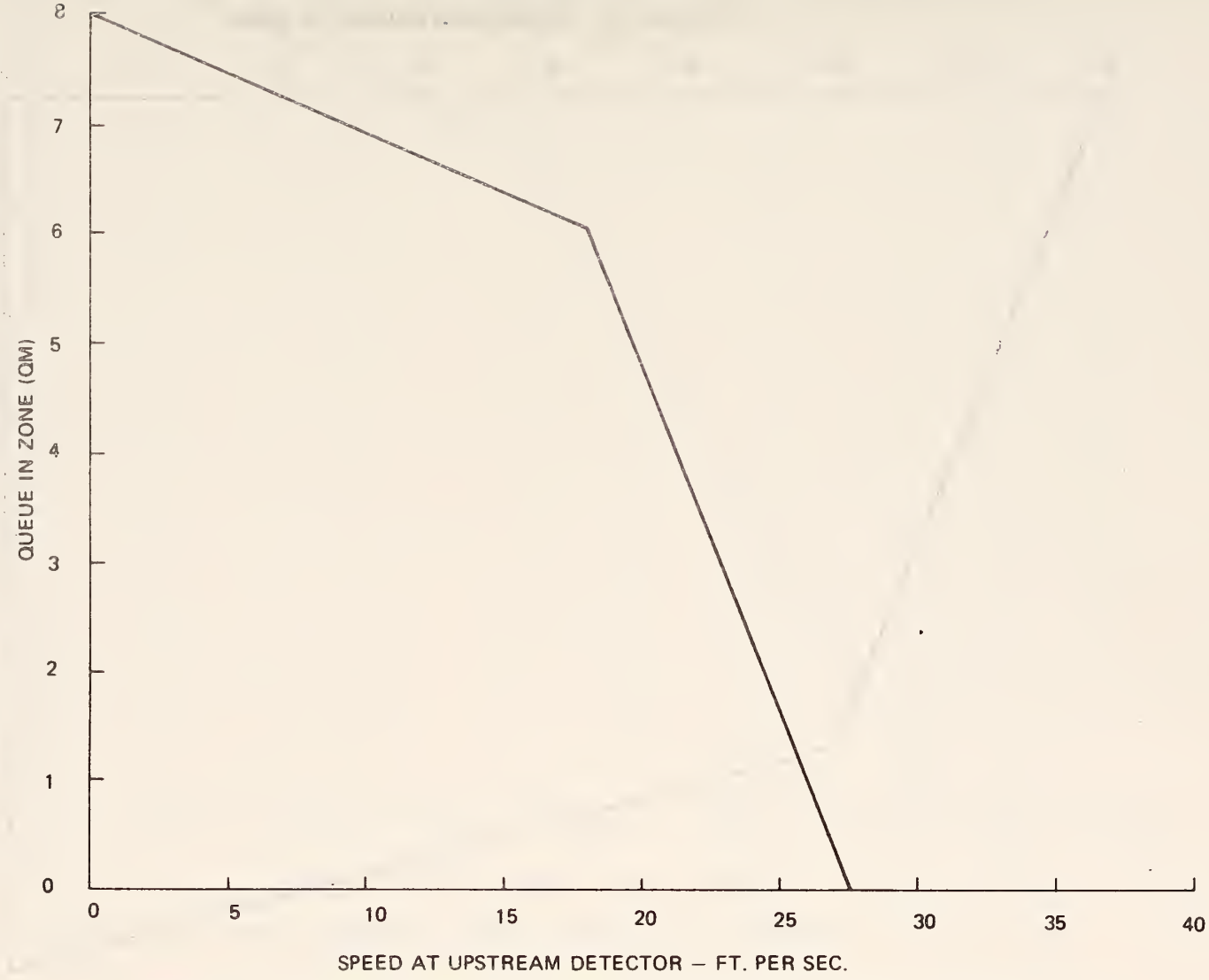


Figure 2-1. Observed Queue vs. Speed Over Detector - Block < 400 Feet Long

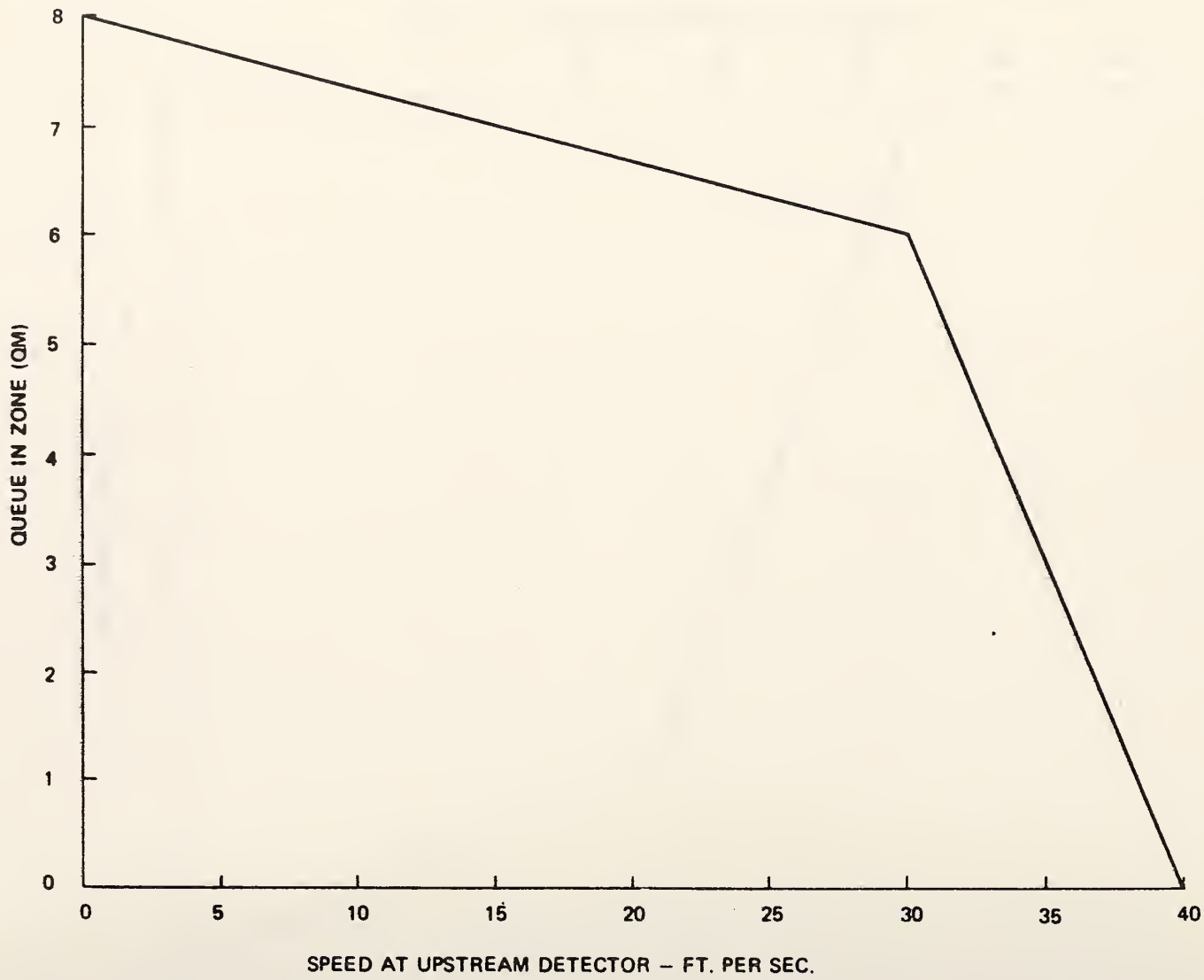


Figure 2-2. Observed Queue vs. Speed Over Detector - Block > 500 Feet Long

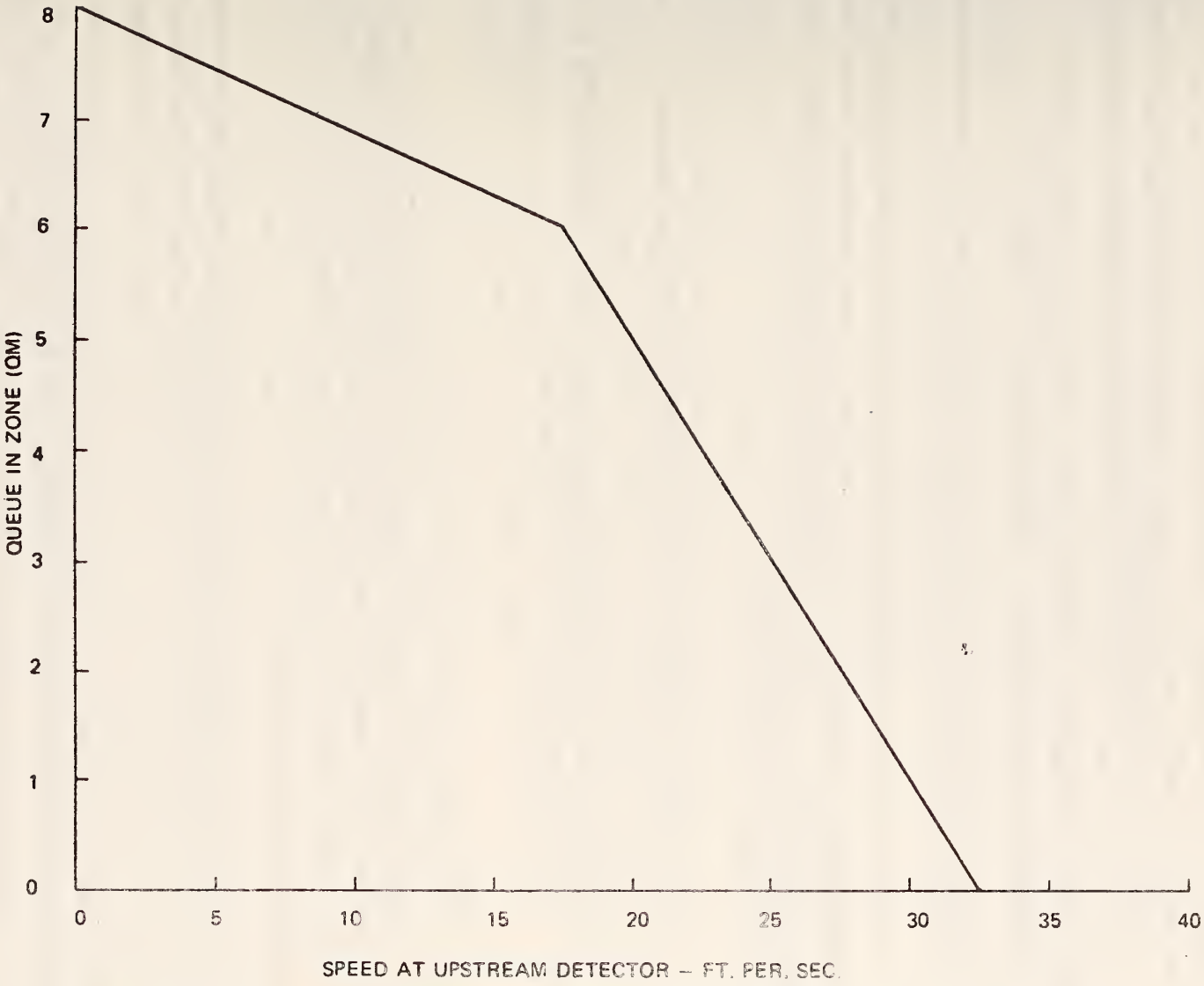


Figure 2-3. Observed Queue vs. Speed Over Detector - Block 400-500 Feet Long

The slowing down algorithm is not used in Zone 2 until the total zone count exceeds the capacity of Zone 0 plus Zone 1, since up to that time none of the cars will have to stop in Zone 2. This also ensures that TP cannot be negative during the formation of a queue in Zone 2.

Whenever a queue is still forming in a zone after the light turns green for the link, the car count in the zone is equal to the queue length in cars minus the number of cars leaving the zone during green. This last number equals CC1 for Zone 1 while for Zone 2 it is given by the capacity of Zone 1 minus the sum of CC1 and the Zone 1 count.

Whenever a car leaves a zone the corresponding zone count is reduced by one.

Since Zone 0 has no downstream detector, there can be no direct count of the cars leaving the zone. Its capacity is only one car; thus the above described slowing down estimation is inapplicable. In order to correct the count in this zone to the greatest extent possible, the following procedure is used:

- At the start of red for a link the zone count in Zone 0 is taken to be 1, if the Zone 1 count exceeds 3 cars. It is taken as 0 if the Zone 1 count is 3 or less.
- Whenever the Zone 1 count exceeds 3 during the red period, the Zone 0 count is set equal to 1.

(1) Queues

Whenever the term "queue" is used without a modifier, the sum of the zone counts within a link at the instant the traffic signal turns green for the phase is implied. Another queue, QCIC, is used for CIC control which is an estimate of the number of cars in the actual stopped queue at green.

If there are no indications of the zones being completely filled, QCIC is simply given by the Zone 0 plus Zone 1 counts. If the smoothed pulse widths at the upstream detector of Zone 1 are so large that Zone 1 is apparently filled, QCIC is equal to the Zone 0 plus Zone 1 counts plus a number representing an estimate of the queue extension beyond the second detector. If both Zones 1 and 2 are apparently filled, QCIC is given by the Zone 0 plus Zone 1 counts plus the capacity of Zone 2 plus a number representing the estimated queue extension beyond the third detector.

(2) Stops

The computation of stops requires a knowledge of the zone counts and an exact determination of phase relationships at all times. It is assumed that no vehicle will exceed the free flow speed for the link in question and that all vehicles will follow a predetermined trajectory based on the number of vehicles already in the zone. The latter assumption is also basic to the entire queue algorithm as discussed previously.

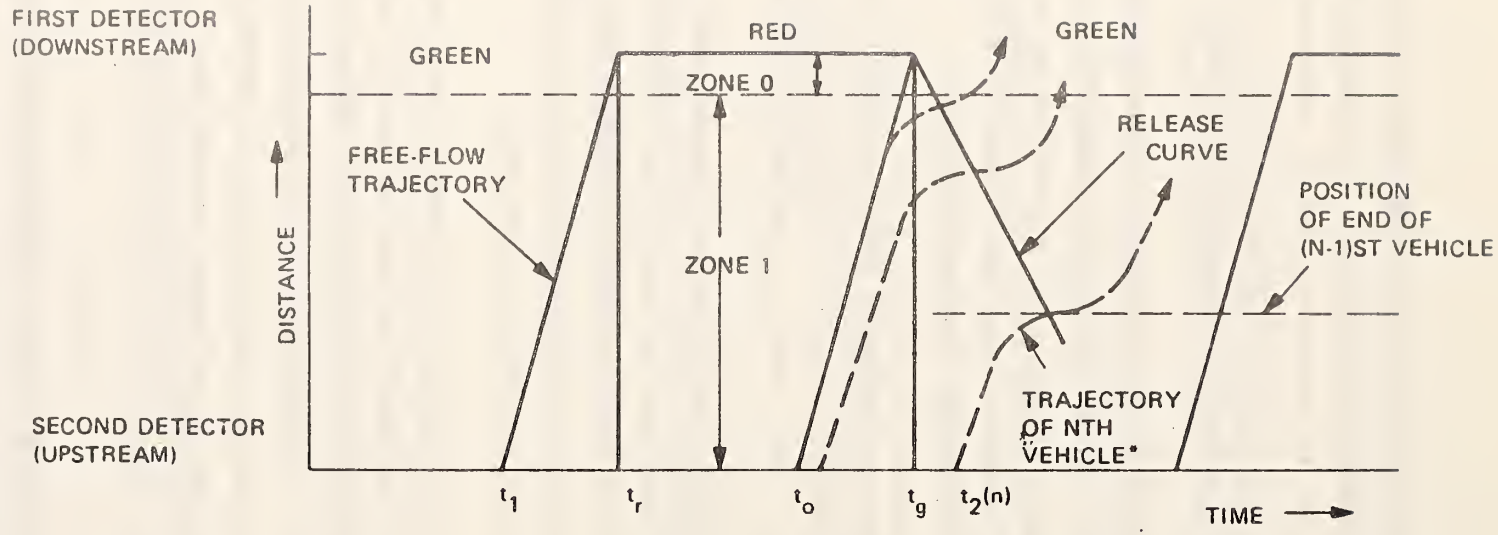
Figure 2-4 illustrates the time-space relationships used in the stops algorithm. In this figure t_r is the time when the light actually changes to red for the link while t_g is the actual time the light changes to green. It can be seen that any car arriving at the second detector before time t_1 will be able to clear the intersection while after t_1 it will have to stop. Thus t_1 is considered to be the "predicted red time".

Similarly if there are no cars in Zone 0 or Zone 1, a car crossing the second detector after time t_o will not have to make a full stop although it may slow down as shown in the uppermost trajectory. Thus, time t_o is considered to be the "predicted green time".

All cars crossing the second detector between times t_1 and t_o will have to stop. If there are cars in Zone 0 and Zone 1 at time t_2, cars crossing the second detector after time t_o will also have to stop. This necessitates defining a time, t_2, known as the "stops threshold time". Cars crossing the detector before time, t_2, will have to stop while those crossing after may slow down, but will not have to stop.

This time, t_2, is a function of the number of cars in Zones 0 and 1. Thus, in Figure 2-4 if there are N-1 vehicles in the queue at time t_g, the (N-1)st vehicle will start moving at the time indicated by the intersection of the "Release Curve" and the "Position of End of (N-1)st Vehicle". If a vehicle crosses the second detector at time $t_2(n)$, it will not have to make a full stop and the same holds true for any vehicle crossing after this time. Thus, this time represents the desired "stops threshold time". However, if the nth vehicle crossed before time $t_2(n)$, it would join the queue and the stops threshold time would be increased.

It can be seen that the stops threshold time, for any number of stopped vehicles, can be obtained by projecting the intersection of the release curve and the end of the stopped queue back to the position of the second detector in the time-space diagram, by means of the trajectory labeled "trajectory of nth vehicle". A table has been prepared giving the time t_2 as a function of the distance of the end of the stopped queue in terms of vehicle lengths.



*VEHICLE THAT JOINS THE QUEUE JUST AS THE LAST OF THE STOPPED VEHICLES STARTS TO MOVE.

Figure 2-4. Time-Space Diagram for Stops Computation

The time t_2 in the table is measured from t_o. This table has been extended to be applicable to three detector links by enlarging the time-space diagram to include Zone 2 with the third detector placed eight car lengths from the second detector. In this case, t_2 is still given in terms of the time from t_o, where t_o is still the predicted green time at the second detector. This table is called DT in the program.

For a two detector link the number of stops for each cycle is determined as described in the following sentences. At the predicted green time, t_o, the sum of the Zone 0 and Zone 1 counts is obtained. This number is used to enter a table giving the stops threshold time for this length of stopped queue. This time is loaded into a STOP1 clock which is counted down each second. If a car crosses the second detector before the STOP1 clock is counted down to zero and before time t_g, the sum of the zone counts is again used to obtain a new stops threshold time. The difference between this new time and the old time is algebraically added to the STOP1 clock. If the car enters after the green time t_g, the number used for entering the table is given by the sum of the zone counts plus the count of the vehicles leaving the link, CC1. CC1 is given by the number of cars crossing the first detector after the green time t_g. The number thus defined represents the total length of the end of the stopped queue before the last car is released from the link.

The stops threshold time is given when the stops clock STOP1 is counted down to zero. The number of stops for the cycle is then given by the total of the Zone 0 and Zone 1 counts plus CC1.

For a three detector link the above algorithm is used as long as the total count in all three zones does not exceed the capacity of Zone 0 plus Zone 1. When the number exceeds this capacity a stops clock, STOP2, is used which is loaded by a number obtained from the same table used for a two detector link. This table is extended to include a queue equal to the capacity of Zone 0 plus twice the capacity of Zone 1.

Since the capacity of Zone 2 is variable and never greater than the capacity of Zone 1, a correction must be made for this factor. The times used for loading and updating the STOP2 clock are found by entering the table with a queue equal to the total car count plus CC1 plus N2, and subtracting from the time thus obtained the extra time required to disperse a queue of N2 vehicles. This dispersed time is found to simply equal N2 seconds since the queue dispersal rate, i.e. the slope of the "release curve", has been found to be very nearly equal to 1 second per vehicle.

Once the stops clock, STOP2, is set, the number of stops for a cycle is obtained when STOP2 is counted down to zero. The stops are then set equal to the Zone 0 plus Zone 1 plus Zone 2 counts plus CC1.

If the intersection is a bus priority intersection, it is necessary to take into account the possibility that the red time for a link on this intersection may be extended. Since a bus extension is automatically inhibited whenever the STOP2 clock is loaded, i.e. when the total zone count exceeds the capacity of Zone 0 plus Zone 1, the correction need only be applied to the STOP1 clock.

If a bus extension is granted before the STOP1 clock goes to zero, the time in the STOP1 clock is increased by the amount of the bus extension. If the STOP1 clock goes to zero before green is displayed for the link (and STOP2 has not been loaded), the total zone count is stored at that time. Whenever a car crosses the second detector, an update for the STOP1, BTDIFF, is calculated and stored. If no bus extension is granted before green is displayed, at green the number of stops for the cycle is set equal to the stored zone count.

If a bus extension is granted before green, the STOP1 clock is loaded with the sum of the bus extension plus BTDIFF and the number of stops for the cycle will be equal to the total zone count when the STOP1 clock is counted down to zero.

F. Delay

The derivation of the algorithm used to obtain delay in UTCS is obtained with the aid of Figure 2-5. Although only two detectors are shown, the relationships will also hold for three detector links simply by inserting the position of the third detector instead of the second detector. One basic simplifying assumption used in this derivation is that the vehicles arriving during the red phase are uniformly spaced. The definitions of the quantities shown in Figure 2-5 are as follows:

QR	=	Total zone count at beginning of red phase
QG	=	Total zone count at beginning of green phase, i.e. "queue"
RR	=	Queue release date across intersection during green phase in seconds per vehicle
DR	=	Duration of red phase in seconds

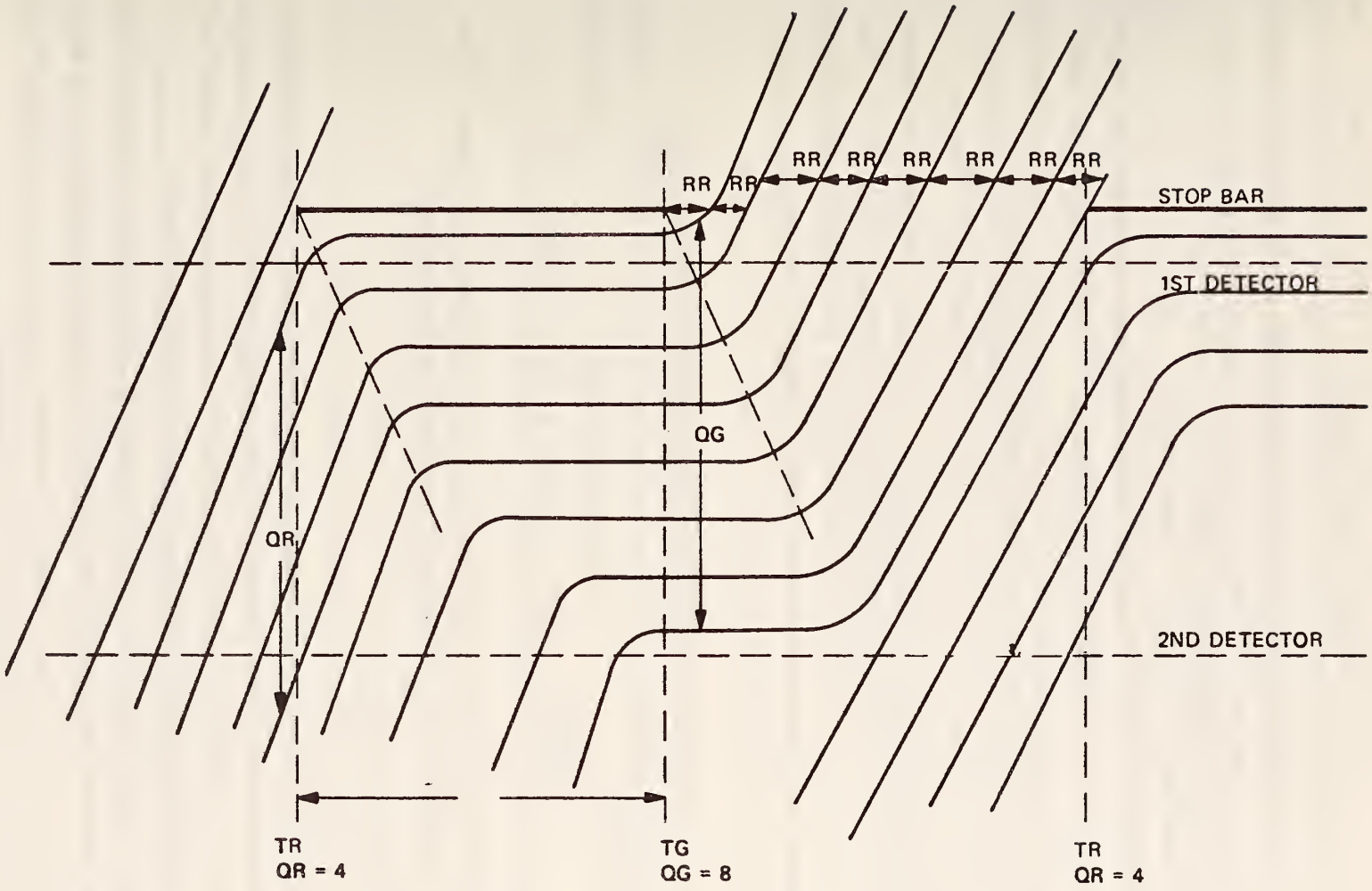


Figure 2-5. Time-Space Diagram for Two-Detector Link

TR = Time of beginning of red phase

TG = Time of beginning of green phase.

As long as the queue formation rate is approximately equal to the queue dispersal rate, the delay for each vehicle forming QR will be closely equal to the red time, DR. Thus, the total delay of these vehicles is QR * DR.

The number of vehicles entering the zones during the red phase is QG - QR. The delay for each vehicle, by definition, is the time that each vehicle stays in the link less the time needed to traverse the link at the free flow speed, FFS. The total time after green taken for the last vehicle to leave the link is QG * RR seconds. The first vehicle which arrives during red leaves the link (QR+1) * RR seconds after green. Thus the average time each of these vehicles leaves is (QG + QR + 1) X RR/2 seconds after green. Similarly the average arrival time for these vehicles is DR/2 seconds before green. The free flow traversal time is D/FFS where D is the length of the link (actually the total distance from the stop bar to the second or third detector). Thus the total delay for all vehicles is

$$\text{Delay} = QR * DR + \frac{(QG-QR)}{2} * \left[(QG+QR+1) * RR + DR\ \frac{2D}{FFS}\right]$$

which can be rearranged as

$$\text{Delay} = \frac{(QG+QR)}{2} * \left[DR + (QG-QR) * RR\right] - (QG-QR) * \frac{D}{FFS}$$

where the term $(QG-QR) * \frac{RR}{2}$ has been dropped since it is negligible with respect to the remaining terms. A negative value of the delay is excluded by the program.

2.2.4 TRAFFIC SIGNAL CONTROL

The computer in the UTCS system replaces the dial drum, in that it generates the interval advance pulses which step the signal control camshaft. For the semi-actuated controllers, the computer generates a yield pulse which the controller uses to initiate the internally timed B-phase vehicle or pedestrian sequences as a function of the existing demand at the controller. Both types of controllers receive a continuous hold signal when the controller is on line. At the initiation of the hold signal, the appropriate relays at the local controller are energized to switch from standby to computer control and the computer transmits advance or yield signals according to the type of controller.

In addition to the two outputs from the computer to the controller described above, a signal representing A-phase green is transmitted from the controller to the computer. This signal is used by the computer to determine if the controller is correctly following the computer-generated advance (or yield) and hold commands.

The computer replaces the District's master controller cycle timing references for all those controllers under computer control. The specific functions which are normally performed by the master controllers in conjunction with the local controllers, and which are taken over and performed under computer control, are:

- Selection of signal timing control parameters (cycle, split, and offset) for each section of controllers
- Timing of controller cycle lengths for all possible operational cycles which may be selected by the computer program
- Maintenance of desired offset relationship at each local controller with respect to the cycle timer currently designated to that controller.

The computer program also accommodates all those time-of-day lane or street direction changes which occur within the network by appropriately changing the selection of control parameters that apply to the streets affected.

A. Cycle Synchronization Before Transformation to Computer Control

When the traffic system is placed on line, computer-timed cycle lengths are synchronized with the corresponding cycle timing reference from the District's master clock before the controllers are transferred to computer control. During start-up, the cycle time count for a given cycle length is not initiated until the master synchronization pulse is received from the corresponding District master controller operating at this cycle length. The single exception to this procedure will be the case where no synchronization pulse is received from a master controller for 125 seconds following start-up. (Normally all pulses will have been received by this time since the maximum cycle length in the District's system is 120 seconds.) At the end of this 125-second period, all cycle time counts that have not been initiated previously will be started, and the computer will proceed to place the controllers on-line.

B. Cycle Synchronization Checks While Under Computer Control

While under computer control, cycle synchronization with the master clock pulses is continuously checked. If the synchronization degrades by more than five seconds in either direction, a flag is set for all controllers using that cycle length. The flag is interpreted by the computer which, in turn, alerts the operator by changing the Master Sync legend on the CRT Intersection Status page from a "yes" to a "no", for any controller using that cycle length. The flag is automatically reset when synchronization is again within tolerance.

It should be noted that an out-of-synchronization condition will not drop controllers from computer control. Internal tests are continuously made which assure computer timing accuracy and stability. Should these tests fail, the system would automatically be placed in Standby. Thus, it is likely that any drifts in the synchronization from the District's master clock, beginning with the initial start-up, will not be due to the computer timing reference.

C. Synchronization of Controller With Computer

After a controller is placed under computer control, it is continuously checked, and corrections attempted, if necessary, to assure that the controller cam intervals are in step with the computer designated intervals. This is determined in terms of the A-phase green return signal which signifies the start of the first controller interval. If the A-phase green return signal is not present within 3 seconds of the computer directed A-phase green, an additional interval advance pulse is transmitted. If the A-phase green return signal is not present by 1 1/2 seconds following the transmission of this additional advance pulse, the controller will be placed in standby, a "controller malfuction flag" will be set, and the CRT failure table will be updated. If the start of the A-phase green return occurs one interval early, a flag will be set to inhibit the transmission of the next sequential interval advance pulse.

If it is inferred from the A-phase green return that a controller is out of step with respect to the computer-generated A-phase green by two or more intervals at any time during a controller cycle, the following sequence will be initiated by the computer:

- Place the controller in Standby
- Set controller malfunction flag

- Update the CRT failure table.

D. Transition Cycles

Transition cycles are used for smoothly transforming from one area control pattern to another, or when a controller is being transferred from standby to computer control. The number of required transition cycles depends on the difference between the working offset and the new, or desired, offset and is determined as follows:

- If the magnitude of the offset difference is less than 2 seconds, no transitional cycle is required.
- If the magnitude of the offset difference is greater than 2 seconds, either one or two transitional cycles are required. The computer will select the quickest way to impose the desired offset, within the bounds that a transitional cycle length must be greater than the minimum cycle length for the section and must be less than twice the minimum cycle length.

The splits during the transitional cycles are apportioned as follows:

- If the intersection has been operating as a critical intersection, the transitional split is set equal to that value which was in effect for the cycle immediately preceding the transition.
- If the intersection has not been operating as a critical intersection, the transitional split is set equal to that value which is to be used after the transitional cycles have been completed.

Transitional cycles will permit a smooth transition of a controller from Standby (local dial control) to computer control even for an out-of-tolerance cycle synchronization condition. This situation may arise if a controller has been in Standby for some time after the traffic system was placed on line (all cycle lengths synchronized). The difference in synchronization will be interpreted as a difference in offset and the transitional cycles will be adjusted accordingly, in bringing the controller in synchronism with the computer cycles.

E. Transformation From Computer Control to Standby

The computer attempts to make a smooth transformation when dropping a controller from computer control to Standby. When a Standby request is made, the computer

waits for the next A-phase green return signal from the controller and counts 7.5 seconds before releasing it. Release consists of removing the hold signal to the controller. This sequence assures that the hold has been dropped while the local controller cam is within its first green interval.

The 7.5-second delay assures that the initial A-phase green phase will be at least that long, whether the local dial cycle length is synchronized with the current computer cycle length or not. If the cycle length is synchronized at the time of release, the controller will fall into the local phase timing sequence on the next cycle beginning with the receipt of the initial A-phase green return. If the cycle length is not initially synchronized, the proper phase timing sequence is automatically picked up on the following cycle, when the green-release key steps the cam out of the first green interval (interval #1).

For semi-actuated controllers, the release to Standby is made at the time that the next yield pulse is transmitted by the computer. This provides a smooth transformation and, at the same time, assures that the minimum A-phase green time is maintained.

F. Semi-Actuated Control

Semi-actuated control is used at intersections within the UTCS network with light cross street traffic. The primary function performed by the computer is to synchronize these controllers with the cycle lengths and offsets which are being imposed on the sections to which they are assigned. All of the vehicle and pedestrian sensing, timing, and control functions required to generate the A-phase clearance intervals and the B-phase passage and clearance intervals remain under the control of the local controller.

The UTCS computer transmits a yield pulse to the semi-actuated controller on a once-per-cycle basis. The controller uses this pulse to initiate one of the following B-phase sequences as a function of the existing demand at the intersection:

- Pedestrian sequence
- Vehicle sequence
- Combination of the above two sequences
- No B-phase sequence (if no B-phase calls are present).

The computer generates a yield pulse which meets the following requirements:

- Maintains the same cycle length at the semi-actuated controllers as that which is in effect at the adjacent controllers in the section.
- Transmits the yield pulse at such a time that the subsequent A-phase clearance intervals and the longest permissible B-phase interval cause the next sequential start of A-phase green to occur at the desired main street offset time. (A yield pulse cannot be transmitted until the preset minimum A-phase green time, after the start of A-phase green, has elapsed.)

The semi-actuated controllers do not require the transitional cycles described above for the non-semi-actuated or pre-timed controllers. Transition, when changing from Standby to computer control and during pattern changes, consists simply of extending or shortening the A-phase green to impose the new offset on the subsequent cycle.

2.2.5 MALFUNCTION DETECTION

The UTCS/BPS program provides for the continuous detection and recording of system malfunctions. In addition, the system reacts so that the effect of these failures on system operation is minimized. For example, if a detector fails, it automatically inhibits MOE computations on its associated link. The inoperative link thereby inhibits CIC operation. If a controller failure is detected, it is automatically released from computer control.

Equipments which are continuously monitored for failures are as follows:

- Controllers
- Vehicle detectors and associated communications
- Bus detector and associated communications
- CPU #1 and CPU #2.

A. Controller Failure Detection

All system controllers are continuously checked by the computer. Failures are identified as to number designation and location via the CRT displays, map displays and printouts.

Pre-timed controller failures are indicated if it is inferred from the A-phase green return that the controller is out of step with respect to the computer-generated A-phase green by two or more intervals at any time during a controller cycle. Thus, any failure in a controller and/or associated equipment (including electronics and communications) which cause the local controller not to track the computer-generated intervals for stepping the controller cams, is detected as a controller failure.

Semi-actuated controller failures are indicated if the A-phase green return is not present during the 0.5-second time period prior to the normal transmission of the yield pulse.

The computer takes the following steps when a controller failure is detected:

- Places the controller in Standby (local control)
- Indicates controller failure on control panel
- Updates the CRT and map display failure status
- Records the failure for 15-minute printout.

B. Detector and Detector Communications Failure Detection

All system detectors (vehicle and bus detectors) with associated communications are continuously checked by the computer. Failures are identified as to type (detector or communication), number designation, and location, via the CRT displays, map displays, and printouts.

(1) Vehicle Detector Failure Detection

Vehicle detector actuations are transmitted to central communications in terms of two-frequency information (Table 3-8). In order to isolate a detector failure (with its electronics) from a communications failure, the computer makes tests on a continuous basis and registers the malfunctions accordingly. The criteria for the two types of failures follow.

A detector failure is indicated if either of the two following conditions are detected:

- Presence has been indicated for a period greater than 12 minutes.
- The detector car counts over its associated controller cycle exceeds a threshold of 32 vehicles.

Both of these conditions are normally indicative of an on-street detector electronics malfunction.

A communications failure is indicated if both of the following conditions are detected:

- Presence has not been indicated at the detector for 3 minutes, and
- Presence has not been indicated over an interval exceeding 16 times the normal vehicle gap length, based on time-of-day volume history for the link.

Both of these conditions are normally indicative of a loss of detector signals to the computer. It should be noted that it is possible that an actual detector failure, such as an open loop, will be indicated as a communications failure.

(2) Bus Detector Failure Detection

Bus detector actuations are transmitted to central communications in terms of three-frequency intelligence (Table 3-8). A communication failure is determined directly by virtue of the three-frequency transmission. The computer continuously checks the state of the Bus Error (BE) output line of the associated receiver in central communications. If an "on" state is not indicated, a communication malfunction is registered.

A bus detector failure is based on the detection of abnormal bus zone counts. The process combines the operation of the upstream and downstream detectors, and isolates the failure to the most probable of the two. The criteria used are as follows:

- If the bus zone count is reset to zero (reset automatically whenever the measured bus zone count is less than zero) over two successive controller cycles, a detector malfunction is indicated for the upstream detector. (Note that when the bus zone count is negative, it signifies that buses are being counted out by the downstream detector and are not being counted in by the upstream detector.)

- If the bus zone count exceeds a threshold (maximum of 20) over two successive controller cycles, a detector malfunction is indicated for the downstream detector. (Note that when the bus zone count is excessive it signifies that buses are being counted in by the upstream detector and are not being counted out by the downstream detector.)

The requirement that criteria 1 and 2 above be evident over two successive controller cycles guards against the possibility of indicating a failure due to spurious bus counts. For example, it is possible that, when two buses which are side by side traverse or are stopped at a detector, spurious counts may be obtained. The two successive controller cycle requirement greatly reduces the probability of indicating such a situation as a detector malfunction.

C. CPU Malfunction Detection

CPU #1 and CPU #2 are checked periodically (once per minute) against each other or separately, depending on how they are started up. If CPU #2 is started up within 2 minutes after CPU #1, the malfunction detection process operates in the Dual mode. If CPU #2 is not started up within the 2 minutes, both CPU's operate in their own single-CPU mode, and continue to operate that way until another start up of CPU #1 and CPU #2 is made satisfying the 2 minutes requirement. A description of the two modes follows.

(1) Dual Mode

The BPS CPU scans the memory and randomly collects a data base. Upon completion, it signals CPU #1. At this point the two CPU's execute the instruction repertoire independently and the answers are compared. If the answers do not agree, the audible alarm is activated and the system is shut down. The computer attempts to place the controllers in Standby using transition cycles. In addition, it attempts to print out a message on CRT #1 as follows:

CPU FAILURE DETECTED AT 13:02.
ATTEMPTING A GRACEFUL SHUTDOWN.
MONITOR CONTROLLER STATUS TO DETERMINE EFFECTIVENESS OF SHUTDOWN.
IF SYSTEM DOES NOT RESPOND USE MANUAL RELEASE.

If the system does not react, indicated by controllers not being returned to Standby (local control), all controllers should be released by the operator by depressing the MANUAL RELEASE pushbutton on the Control Panel. About 2 minutes should be allowed for a "graceful" shutdown.

(2) Single CPU Mode

Each CPU exercises the instruction repertoire on a fixed set of data. The results are compared with pre-stored answers. The three possible system reactions to a CPU failure are as follows:

- CPU # 1 is operating alone. In that case a system shutdown as for the Dual mode is attempted.
- CPU # 1 and CPU # 2 are both operating and CPU # 2 fails its test. CPU # 1 then shuts down CPU # 2, inhibits BPS operation, and continues with UTCS operation.
- CPU # 1 and CPU # 2 are both operating and CPU # 1 fails its test. In that case a system shutdown as for the Dual mode is attempted.

D. CPU Malfunction Detection Via Control Panel

CPU # 1 and CPU # 2 malfunction detection is also in effect via the control panel. The panel looks for a change of state from CPU # 1 within every 2-second interval. If this state change is not received, signifying that the computer is not functioning normally, the CPU # 1 malfunction light will be turned on, the audible alarm will be activated, and the hold signals to all controllers will be released, placing them in Standby. The panel also looks for a discrete signal from the computer which is indicative of CPU # 2 status. If it changes from a normal to a failed condition, the CPU # 2 malfunction light will be turned on. CPU # 1 will, in turn, inhibit BPS operation.

SECTION 3
STREET INSTALLATION DESIGN

3.1 INTRODUCTION

This section presents the factors, studies, surveys and tradeoffs which must be considered and performed in order to generate a street installation design (including curbside installation specifications) which will be cost-effective and will interface vehicle flow with central control in an optimum manner. Also presented is a description of the final UTCS street installation design, the factors affecting the design, and a typical curbside installation drawing, which resulted from the UTCS studies and tradeoffs.

3.2 GENERAL

3.2.1 PRELIMINARY SURVEYS AND STUDIES

Preliminary surveys and studies are required to select the intersection complex that can best be served by a computer-controlled traffic system. Surveys may also result in intersection geometric and signalization design improvements which would ultimately enhance computer-controlled operation. The information can be extracted from TOPICS reports, when available, and by supplementary surveys and studies. If no data exist for an intersection, or if extensive changes have occurred at the intersection, a complete study of the intersection will be required to develop new basic data for the analysis.

The basic data should consist of the static and dynamic features of the intersections involved. The static data should include the intersection physical features such as roadway type and condition, cross-section information, right-of-way width, number and width of lanes, and the time-of-day existing parking regulations. Existing signal equipment should be catalogued according to manufacturer, model type, phasing and method of control. The dynamic features of the intersection should include the operational characteristics of the vehicle flow counts, pedestrian counts, turning movements and classification counts. From these data, a determination is made of the peak-hour flow, off-peak hour flow, and the average daily traffic count.

The collected data are used to select the intersections to be included in the computer-controlled complex. If initial cost is a factor, a nucleus of intersections may be selected for immediate implementation; other sections can subsequently be added on a modular basis. The survey of traffic patterns and geometric considerations also determine the breakdown of network sections and arterials. Traffic patterns may also determine the type of control to implement in some areas. For example, if the traffic patterns in a given section of controllers are highly predictable on a time-of-day basis, it is not advantageous to instrument the intersections for traffic-responsive operation. Operation limited to time-of-day control will result in considerable savings in detectorization.

The traffic data are also used to determine which intersections are to be instrumented for CIC operation. Intersections for which CIC operation is desirable are those exhibiting heavy fluctuating demand on two or three phases.

Both static data (intersection physical features such as right-of-way width, number of lanes, and parking regulations) and dynamic data (traffic flow counts, pedestrian counts, turning movements and classification counts) are required to implement the Signal Optimization Program (SIGOP) for generating traffic patterns off-line for use in traffic-responsive operation. System outputs, gathered when the system is initially on line, are fed into the SIGOP program to generate the desired patterns (see Section 6).

Site surveys are required to generate the curbside installation specifications and drawings. A survey of municipal and town ordinances relating to street modifications and installations is also required. Local ordinances may affect the selection of the type of system components that will be used as well as the actual installation.

3.2.2 CONTROLLER SELECTION

An evaluation of existing controllers and controller subsystems, which may or may not be included in the computer-controlled complex, is essential in determining the final system configuration. Controllers which are obsolescent or are near the end of their operating life should be replaced. The type of controller chosen for replacement is determined by both traffic (results of surveys) and system considerations. This section describes the alternatives in using pre-timed and actuated controllers in the computer system. It also describes the alternatives with regard to adapting existing Master Controller (MC) subsystems into a computer-controlled complex.

Regardless of the type of controller used, when it is under computer control, by definition, its cycle length and its offset are determined by the computer. A fully-actuated controller, therefore, when it is under computer control, will operate semi-actuated with one of the phases designated as the main street for coordination purposes.

In the event of a computer or communications system failure, a back-up mode of operation must be provided. The back-up mode may range in complexity from single cycle, uncoordinated operation through various degrees of coordinated, variable cycle, variable offset capability. In general, a back-up system that provides the same capability that existed before the computer system was introduced will be satisfactory. In some cases, however, it may be desirable to provide signal synchronization where there previously was none in order to anticipate future requirements.

Feedback from each intersection controller is required for failure monitoring. This function is usually accomplished by transmitting the A-phase green interval back to the computer. Additional intervals may be returned for closer controller monitoring at the cost of additional communications channels. However, this option is difficult to justify under normal circumstances.

A. Pre-Timed Controllers

Pre-timed controllers make up the bulk of present-day traffic systems. In simple installations, controllers operate independently, with cycle and offset synchronization maintained by synchronous operation of dial motors at power frequency. In more sophisticated systems, controllers are linked by wire or radio communication, which may provide a single or several background cycles and offsets for synchronization.

Under computer control, the dial of a pre-timed controller is disconnected from the drum step motor, which is then activated directly from the computer. This is accomplished by two signals from the computer via the communications system designated as the hold and advance signals. The hold signal is a steady signal that operates a relay that disconnects the dial unit from the drum for as long as the controller is under computer control. The advance signal consists of pulses, normally about 1/2 second long, that activate the drum step motor. In this mode of operation, therefore, all intervals of all controllers are determined and controlled from the computer. The interval lengths are usually determined by the signal pattern that is selected for the section or controller group on the basis of sensor data or other criteria, and are fixed for each pattern.

For many intersections, fixed-interval control may be adequate. At certain critical intersections having a heavy fluctuating demand on two phases, however, it is advantageous to be able to apportion the green time to match the demand. This type of "critical intersection control" (CIC) can be provided with a pre-timed controller by installing sensors at the approaches to the intersection. The sensor data are transmitted to the computer which then varies the split at the intersection on a cycle-to-cycle basis.

Another technique for providing local traffic responsiveness with a pre-timed controller is to program the computer to operate it as a semi-actuated controller. This is done by installing sensors on the minor phase approaches as for a semi-actuated controller. The sensor data are transmitted to the computer, however, instead of to the controller. The computer can then hold the controller in A-phase green indefinitely until a call is received on the minor phase. This technique permits an existing pre-timed controller to serve as a low-cost temporary substitute for a semi-actuated controller at an arterial intersection with low cross street demand.

In the event of a computer or communications system failure, pre-timed controllers operate on their internal dials. The hold signal will drop out and the dial resynchronizes itself to the drum in the normal manner. In this back-up mode, a range of operating capability can be provided depending on the requirements of the intersection.

During computer operation, the usual procedure is to keep the dials running, possibly with synchronization from the computer. This can be accomplished by periodically sending out a synchronization pulse that is formed from a combination of the hold and advance signals. Logic circuitry in the controller adapter keeps the synchronization signal from affecting the normal operation of the controller. If a failure disables the computer but leaves the communications system intact, the synchronization pulse can be sent out manually from central control. If a communications failure occurs, the dials remain synchronized for an indefinite period, barring any momentary power failures. During this period, of course, operation is limited to one cycle length and one offset value.

A higher level of back-up capability may be required at certain locations. For example, an arterial carrying heavy commuter traffic needs an inbound and outbound progression during peak periods and an average offset at other times. One method of

providing one cycle length and three offsets with pre-timed controllers would be to install a multi-wire interconnect cable, using a conventional master controller dial with the offsets switched manually or by a time switch. The cost of this approach is difficult to justify for back-up operation only.

Offset change capability can also be provided as a back-up mode without interconnecting cable between individual controllers, using the technique shown in Figure 3-1. An additional dial called a "local master dial" is used at each intersection, taking the place of the remote master dial in a conventional master controller system. Offset changes are made on a time-of-day basis by a time switch which is also part of the back-up package at each intersection. During normal computer operation, the "local master dials", although not in use, will be maintained in synchronism by the computer as described above. During the back-up mode the local master dial can also be synchronized manually, provided the communications system is still operating.

The primary advantages of using pre-timed controllers in the computer system are their low cost and high reliability. The adapter unit required is also simpler than that required for an actuated controller. Local traffic responsiveness can be provided either with CIC operation or the "pseudo-actuated" operation described above.

The disadvantages of using pre-timed controllers are that local traffic responsiveness is achieved at the cost of additional communications channels to carry sensor data to the computer, and additional software complexity. Also, this capability cannot be provided in the back-up mode of operation. An additional disadvantage at some intersections is that with a pre-timed controller it is impractical to provide a phase-skipping capability.

B. Actuated Controllers

Fully-actuated controllers, by design, operate independently of other controllers in a system. Fully-actuated controllers must be modified for semi-actuated operation before computer control can be implemented. This is accomplished simply by setting a switch in the controller for continuous recall on the desired major phase. If accomplished by a discrete signal through the computer in conjunction with a controller modification unit, the controller can be made to revert back to fully-actuated control when released from computer control.

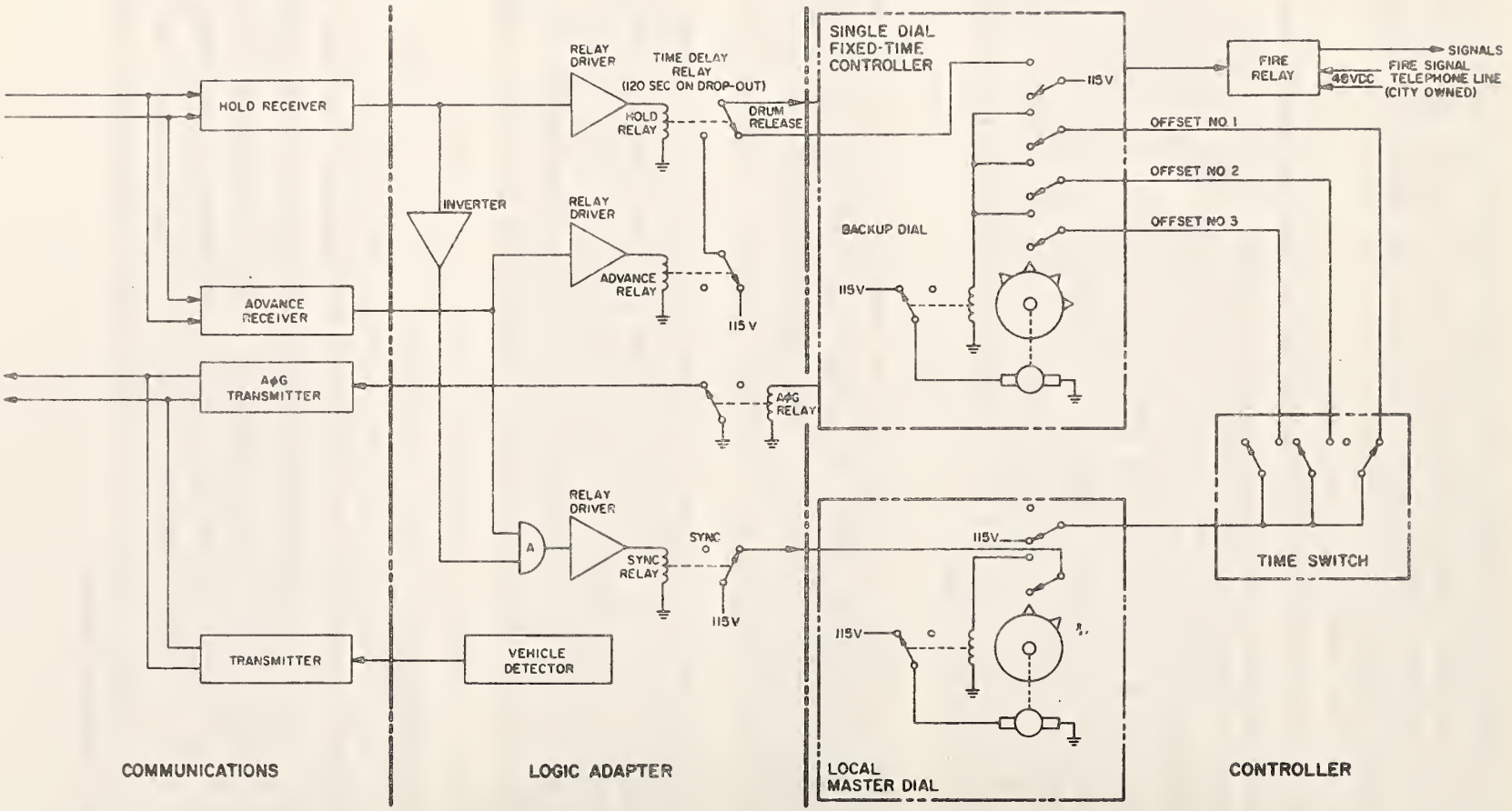


Figure 3-1. Equipment Configuration for Fixed Time Controller

For semi-actuated controllers, and for fully-actuated controllers modified for semi-actuated operation, the cycle length and offset are controlled, when under computer control, according to a timing pattern selected for the section. Computer control is accomplished by means of the hold and advance signals from the computer, as illustrated in Figure 3-2. Through the adapter unit, the hold signal is applied to the A-phase hold input of the controller, preventing it from yielding to calls. Coordination is accomplished by dropping the hold signal momentarily, forming a "yield" pulse, at the proper offset time. If a minor phase call has previously been received, the controller will advance to the minor phase. In order to preserve the cycle length, the time spent in each minor phase is limited by means of advance pulses applied to the "force-off" input to the controller. These force-off pulses cause the controller to advance to the next minor phase if there has been a call on that phase. If there has not, then the controller skips the phase and returns to A-phase. If a particular phase has very light traffic, the controller can advance ahead of the computer force-off command. Thus the unused B-phase green time, for example, would be utilized by the C- and/or A-phases.

A controller "test" mode is usually incorporated into the controller adapter and the computer program. If no controller cycling occurs for an interval determined by demand or time-of-day, the computer issues a test command that imposes calls on all actuated phases. The computer then monitors the controller response by means of the A-phase green feedback signal.

Critical intersection control, that is, cycle-to-cycle split changes to match demand, can also be accomplished with an actuated controller under computer control. Additional sensors are required upstream of the intersection on each approach, to measure the free stream demand. The data from these sensors are returned to the computer, unlike the sensor data used for providing calls to the controller. The computer then varies the end points of the minor phase intervals by means of force-off pulses to match the demand.

As in the case of pre-timed controllers, the nature of the back-up mode will vary according to the degree of coordination and offset change required. If the intersection is sufficiently isolated, back-up operation could be either fully actuated or semi-actuated with A-phase recall and minimum green. Back-up coordination with a single cycle and offset can be provided by a back-up dial, or synchronizer. The back-up dial provides the permissive yield pulse while the controller maximum settings provide the

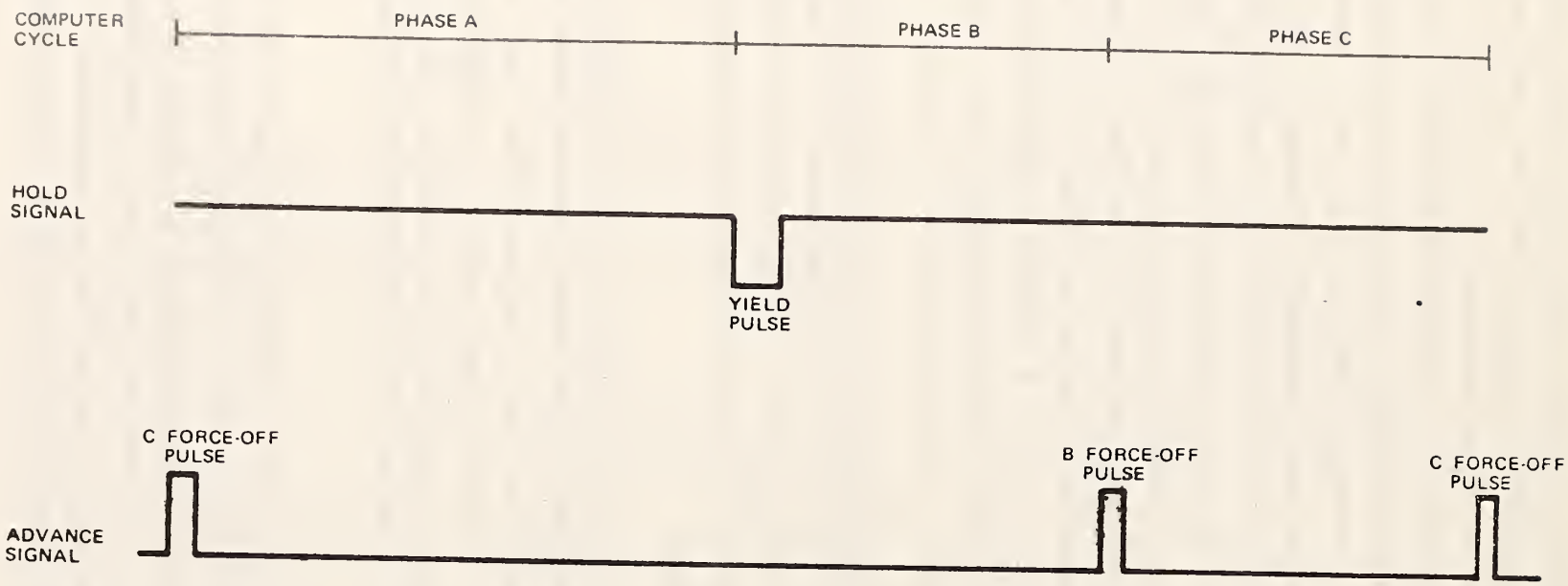


Figure 3-2. Computer Control of an Actuated Controller

actuated phase force-offs. This dial can be maintained in synchronism by the computer during normal operation, and remains synchronized to the AC line for an indefinite period after a communications failure that prevents manual re-synchronizing from central control.

Offset change capability can be provided in the back-up mode by the use of local master dials and time switches as described in the previous section. Figure 3-3, which is analogous to Figure 3-1, shows how this technique is applied to a two-phase semi-actuated controller.

The primary advantage of using actuated controllers in the computer system is that they retain most of their local traffic responsiveness while under computer control. Another significant advantage is the ability to skip phases when the demand permits. This feature is particularly useful where there are heavy left turn movements; capacity can be increased by skipping or terminating one of two left turn movements when there is no demand. The logic operations and the sensor data processing required to provide this capability are performed in the controller, which reduces the number of communication channels and the computer processing required. Clearance intervals are also timed in the controller. The fact that this processing is performed at the intersection also means that the traffic-responsive capability is retained in the back-up mode.

The main disadvantage of actuated controllers is their higher cost. They are also more complex and require more complex adapter units than pre-timed controllers, and may require more maintenance.

C. Master Controller (MC) Systems

This section describes the adaptability of existing master controller systems to digital computer-controlled, centrally located, traffic systems.

MC systems, because of the limited data processing capacity of their analog circuits, are limited to four sensors that provide two independent volume counts to the master controller. The master controller can select six cycle lengths, five offsets and three splits. However, the offset and split selections are dependent on the cycle length chosen so that the number of independent control strategies that can be selected is limited. Although these systems can theoretically be applied to grid configurations, they cannot operate effectively there, primarily because of the limited number of sensing points. Reasonably successful operation has been achieved along arterials by means of very tight green band control which essentially ignores the demand on the cross streets. The small

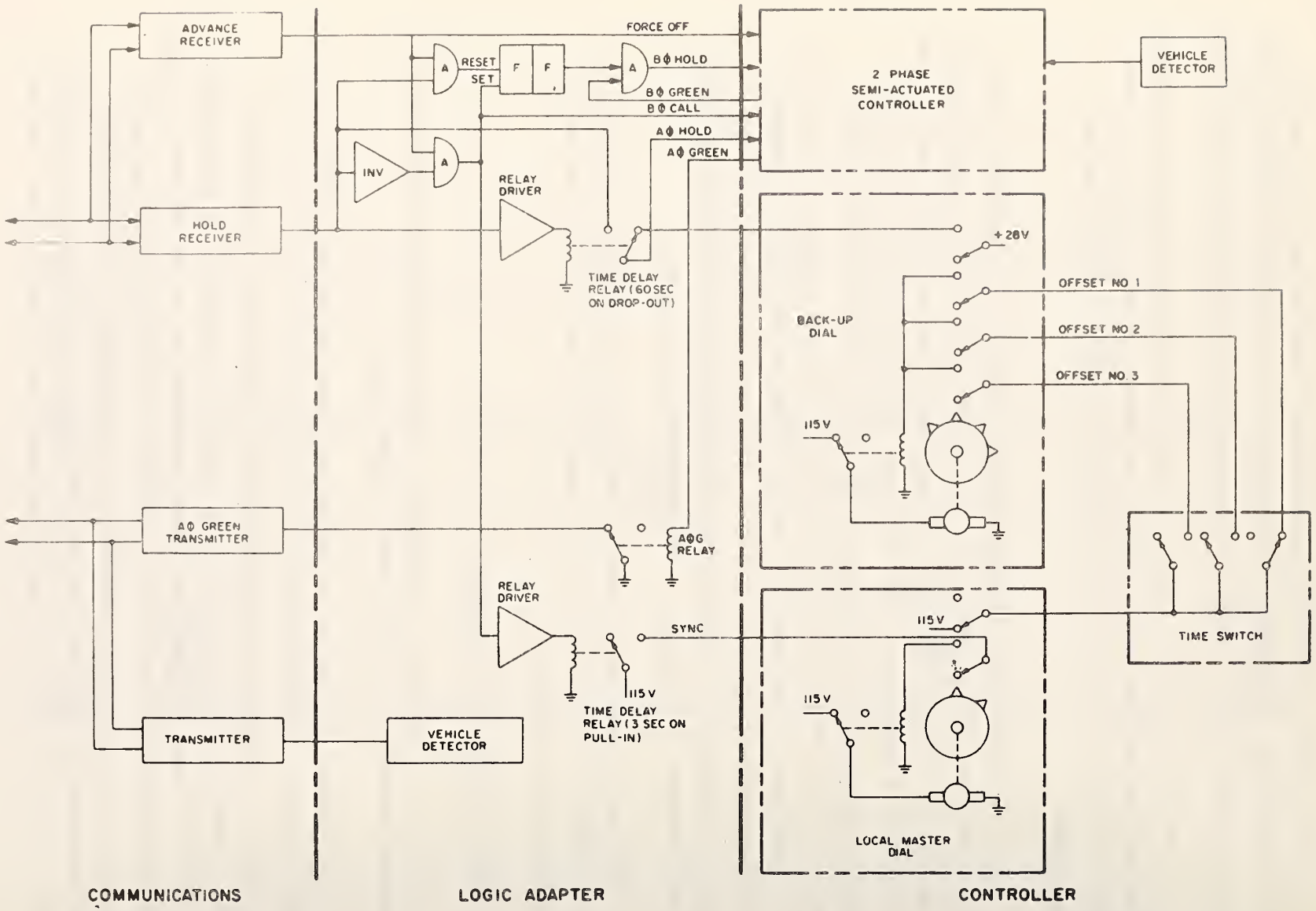


Figure 3-3. Equipment Configuration for Semi-actuated Controller

number of sensing points is still a problem, however, because it allows the system to choose the wrong strategy for certain traffic conditions. For example, if there is an incident upstream of the detector station, the system senses a low volume, which results in a high speed offset for the entire system. Similarly, when rain causes volume to decrease, a higher speed offset results which causes the ends of platoons to be cut off.

In spite of their limitations, existing master controller systems represent a considerable investment in equipment and interconnect which should be utilized in some way. There are four alternate approaches to adapting these systems to computer control. They vary in the extent to which the existing controllers, masters and interconnect cable are utilized. These alternatives are:

- Retain master controller systems intact as part of primary system (minimum new equipment). The central digital computer selects one of the six cycles and one of the five offset patterns that have been set into the MC system. The selection is made on the basis of new detectors to be installed, thereby circumventing one of the main shortcomings of the MC system. The selection is imposed via the existing offset pattern lines and the MC cycle generator as shown in Figure 3-4. In addition, as shown in Figure 3-4, a MC reference pulse is provided to the computer so that a once-per-cycle correction can be imposed on the MC system to slave it to the computer background cycle. This prevents drifting between adjacent sections so that section locking may be implemented. The corrections could be limited to 17 percent change per cycle if desired. In addition to the detectors, the A-phase green interval of each controller is returned to the computer for failure monitoring. The detector and A-phase green returns to the computer by way of the MC reference and cycle signal lines. FDM multiplexing at frequencies distant from the 400-Hz reference signals would be employed. Thus no modifications are required to the existing MC controllers, master or interconnect. Equipment to be added consists of detectors, detector and A-phase green communications, and equipment added to each master as shown in Figure 3-4.

  With this alternate the existing MC system serves as the backup to the computer. However, a considerable degree of commonality between the

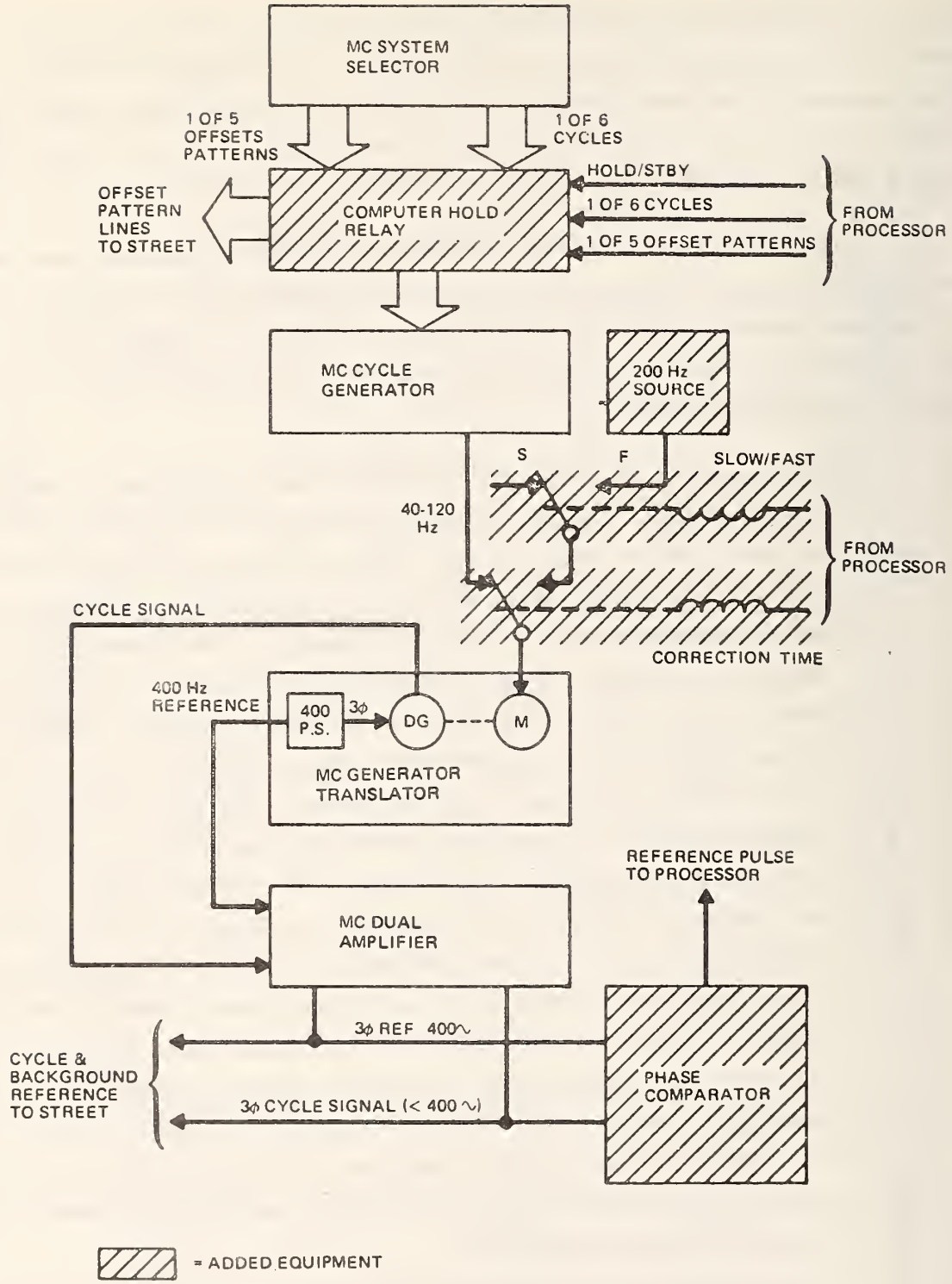


Figure 3-4. MC System Modification

computer and back-up systems exists. Failures common to the two systems are a potential problem area. In addition, modification of the signal patterns cannot be accomplished by software changes. Knob settings must be altered in the master and the controllers to change patterns. Another disadvantage of this approach is that neither critical intersection control nor actuated operation via the computer is possible because there is no control over individual controllers.

- Replace MC systems completely (least use of existing equipment). All existing MC controllers, masters and interconnect are removed. Pre-timed and actuated controllers and detectors are installed as required. New interconnect and back-up systems are installed as described under pre-timed and actuated controllers above.

  The advantages of this most costly* approach are:

  - Complete use of the central computer capability
  - Ability to control intersections and drop controllers off-line individually
  - Improved maintenance program because of commonality with rest of system and elimination of MC equipment.

- Replace MC systems except for cable. This alternate is very similar in its advantages to the complete replacement described above. The existing MC cable is used for the communications interconnect for the new equipment.

  This approach is viable only if the existing cable is sound and contains enough conductors to accommodate the channels required for up to 35 controllers and about the same number of sensors.

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*The cost penalty of this approach can be reduced either by making use of the MC systems outside the computer system or by selling the equipment.

- Retain the MC systems intact as a back-up. This alternate requires the installation of new communications equipment and adapters at each MC controller and new detectors so that the full capability of the computer may be realized using existing controllers. Controller adapters permit operation of existing controllers as pre-timed or semi-actuated while under computer control. Either the existing MC cable or new cable to be installed may serve as the computer system interconnect.

  The existing MC system is retained and serves as a back-up interconnected system.

  A possible disadvantage of this approach is that the MC controllers may no longer meet the requirements of the intersections. If a significant number must be replaced, the cost advantages of retaining the MC system are diminished.

Master controller systems having a more limited number of control strategies (for example, those utilizing two independent sensing points and three independent cycles and offsets) impose the same alternatives as the more complex systems previously described. However, these systems use conventional pre-timed and semi-actuated controllers which may be utilized in a computer-controller system by the addition of a relatively simple adapter unit.

3.2.3 DETECTOR SELECTION

Vehicle sensor or detector actuation provides the data base from which all measure of effectiveness (MOE) parameters are computed, and from which traffic responsive system operation is implemented. The two basic quantities required are vehicle count and presence (detector on-state for a single vehicle)*. Four generally used detector types are the inductive loop detector, the magnetic detector, the ultrasonic detector and the Doppler radar detector.

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*Speed and occupancy are derived from presence. If a detector yields speed directly, occupancy is derived from the speed and accumulated vehicle counts, or volume.

A. Loop Detector

The loop detector consists of the detection loop, a lead-in cable, and its associated electronics. The loop and lead-in cable are embedded in the roadway in saw-cut slots. The loop consists of a number of turns of 14-gauge or 16-gauge wire in the form of a rectangle. The rectangle is centered in a lane and covers a major portion of its width. The lead-in cable is connected at one of the corners of the rectangle and runs to its associated electronics located in nearby controller or associated electronics cabinets. Slots are filled in with an epoxy sealer, level with the roadway surface, after the loop and lead-in are installed.

The loop detector is presently one of the most widely used devices for sensing vehicle traffic and converting the information into an electrical signal usable by other traffic monitoring and control equipment. Three types are in use: the self-tuning detector, the bridge-balance loop detector, and the phase detector. They all, however, operate on the common principle that a change in inductance of the roadway loop is caused by the presence of a vehicle and is converted by the electronics to an electrical pulse of duration proportional to vehicle presence over the loop.

The loop detectors have cost and operational advantages as follows:

- Low-cost electronics
- Low installation costs (no poles or cross arms)
- Low maintenance costs
- High reliability and life
- Well-defined detection zone
- Insensitive to ambient light levels, heavy rains, snow, fog, wind, or ambient noise levels.

A disadvantage of the loop detector is that the lead-in cable forms a portion of the total loop impedance, and variations of cable self-capacitance and inductance, due to temperature and moisture, affect its sensitivity. The detector is normally adjusted for maximum sensitivity during installation, but can degrade during operation. However, experience has indicated that satisfactory long-term operation can be attained by limiting lead-in cable lengths to less than 750 feet.

B. Magnetic Detectors

The magnetic detector consists of a multiturn coil of wire (60,000 turns on a 1/2-inch diameter hypernik) wound on a ferromagnetic core, a lead-in cable, and associated electronics. The core is about 2 inches in diameter and 18 inches long. It is encapsulated in a watertight jacket, which is embedded in the roadway together with its lead-in cable. The lead-in cable runs to its associated electronics in nearby controller or associated electronics cabinets. The coil is not energized electrically and is therefore passive. With no vehicle present, the core essentially sets up a magnetic field which conforms to the earth's field. Uncompensated detectors respond to flux changes in an area as large as 15 feet in diameter. Compensated detectors, suitable for single-lane detection, cover a range of 6-1/2 feet laterally. Operation of the magnetic detector depends on sensing flux-density changes (of the order of 10 webers/cm^2) when vehicles cross the field. These field changes produce peak output voltages at the terminals of the sensing coil in the range 0.002 to 0.05 volt depending on sensor configuration, sensor location, and vehicle signature. The basic frequencies contained in the trace signature of a vehicle are indicative of the speed of the vehicle crossing the sensor. The amplifier circuits in the electronics are designed to yield detector outputs proportional to speed.

The cost and operational advantages of the magnetic detector are similar to those of the loop detector previously described, except that its detection zone is not as well-defined, which leaves the system open to false actuations by flux changes other than those due to vehicle movement. It has the further disadvantage that output speed accuracy is critically sensitive to electronics gain and band-pass characteristics and long term changes will lead to accuracy degradation.

C. Ultrasonic Detectors

The ultrasonic detector consists of transmitting/receiving transducers, a lead-in cable, and associated electronics. The transducer sensing unit is mounted on a mast or a span wire over a traffic lane, or it may be mounted by the side of the traffic lane on a structure at the shoulder of the road. The lead-in cable is carried via the mast or span wire to its associated controller or electronics cabinet.

There are two types of ultrasonic detectors in use, the speed-responsive and the presence-responsive. The presence-responsive type is currently more widely used. The speed-responsive detector operates on the Doppler principle, transmitting acoustical energy at a frequency of approximately 18 kHz. The shift in frequency between the transmitted and reflected signal caused by a vehicle crossing the beam of acoustic energy is directly proportional to the vehicle speed. The detection of this difference frequency is also interpreted as a vehicle count. The presence-responsive type operates in the same manner as conventional radar and sonar equipment. Energy is beamed as a train of pulses in the 19-kHz range. The reflected signals from the passing vehicle are amplified and gated with respect to time, in terms of the speed of sound in air (1 foot per millisecond), so that the detector output signal is indicative of vehicle count as well as presence (or dwell) over the target area.

Ultrasonic detector installations are generally more costly than either loop or magnetic detector installations. In addition, reliability and life are not as good as either the loop or magnetic detectors. The detection zone is not as well-defined as that for the loop detector. This limitation may result in marginal operation when sensing single-lane traffic. Ultrasonic detectors yield satisfactory performance and may be the best choice for installations on highways and freeways where breaking into the roadway may not be possible, or may be too costly due to existing highway construction and design.

D. Doppler Radar Detectors

The Doppler radar detector consists of a transmitting/receiving antenna, lead-in cable, and associated electronics. The antenna unit is mounted on a mast or a span wire over a traffic lane, or it may be mounted on the side of the road so that radiation is broadside.

The Doppler radar detector transmits CW power (0.025 to 0.1 watt) in the 2.45-GHz range. When a vehicle crosses the path of the transmitter, the reflected signal contains a Doppler shift which is detected by the sensor. The signal includes a low-frequency portion, interpreted as a vehicle count, and a high-frequency portion which is indicative of vehicle speed.

Doppler radar detector installations, like ultrasonic detectors, are more costly than either loop or magnetic detector installations. Reliability and life are comparable to those of the ultrasonic detector, but not as good as the loop or magnetic detector. The detection zone definition is satisfactory, but not as well-defined as that of the loop detector. The radar detector provides the most accurate speed information of the four detectors considered. Like the ultrasonic detector, the radar detector may be used to advantage in installations where breaking into the roadway is not possible or desirable.

3.2.4 SELECTION OF DETECTOR LOCATIONS

The selection of detector location is influenced by competing requirements to obtain adequate traffic parameter data and to keep costs low. A cost-effective solution for detector siting is obtained by developing general guidelines and then using data and observations at each link and intersection to classify intersections and modify the guidelines for local conditions.

Decisions on link* instrumentation are made by classifying links into the following general categories:

- Grid area: A region which possesses a substantial number of links with high occupancy, density, and queue lengths for important parts of the day and in particular during the peak hours
- Major arterial: A major volume-carrying street crossed by many streets which carry substantially lower volumes

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*A lane between two adjacent intersections which is intrumented with one or more vehicle detectors. An approach to an intersection may have one or more links instrumented.

- Critical intersection: The crossing of two or more links carrying high volumes through an intersection which is at or near saturation for substantial periods and where, as a result, short-term adjustment of split becomes critical

- Special sources: The source locations which are significant monitor points for demand flows, such as approaches from bridges, tunnels, freeways, etc.

Table 3-1 shows a way in which links may be instrumented. In a grid area, representative links (indicative of the dominant characteristics of traffic flow) should be instrumented to yield volume, occupancy and speed parameters. Links within the grid area, which are associated with critical intersections and frequently saturate, should be instrumented for all MOE parameters.

TABLE 3-1. AREA MOE REQUIREMENTS

Classification	Traffic Parameters to be Monitored	Relative Detector Density	Preferential Orientation of Most Detectors
Grid	Volume, occ., speed	Representative links	None
Major arterial	Volume, occ., speed	Representative links	On artery
Critical intersection	All*	Each link	None
Special sources	Volume	Representative sources	Direction of flow

*Includes queue, stops and delay in addition to volume, occupancy and speed.

The major arterials should be implemented with detectors principally in the direction of the arterial. The traffic parameters available on representative links should be the same as those for a grid. At critical intersections, however, a full set of traffic parameters should be made available.

For lane selection, significant cost savings results if a representative lane can be selected for each signalized block to measure the dominant characteristics of the traffic flow. For example, if a straight-through movement is characterized by longer queues and slower speeds in one lane, that lane would be selected as a basis for both control law decisions and MOE studies. Where turning movements are specifically signalized, the appropriate lane most representative of this movement should be detectorized to provide traffic-responsive capability for this movement.

The selection of lanes to be instrumented thus involves study and observation of each of the links. Where it is difficult to make a clear cut selection, at least one detector is also sited in a parallel lane so that a comparison of traffic parameter measurements between the two lanes may be used to confirm the initial decision or determine whether the alternative lane should be instrumented.

A. Detector Density

The number of detectors to use on an instrumented lane and their spacing are also influenced by the competing requirements to obtain adequate traffic parameter data and to minimize costs. Theoretically, the closer the detector spacing and the greater the number of detectors used, the more accurate the determination of the parameters. In practice, satisfactory performance can be achieved with a limited number of detectors. This is so because meaningful traffic parameters are computed over relatively long periods, that is, over controller cycles and 15-minute periods. Smoothing of the detector outputs

as well as smoothing of the computed parameters on a cycle-by-cycle basis results in considerable averaging of errors due to instrumentation and to unpredictable events such as lane changes, speed variations within a lane, lane blockages, pedestrian friction, garage friction, etc.

A lane instrumented with a single detector can be implemented to yield the desired traffic parameters, including volume, speed, occupancy, queue, stops, and delay. Lanes instrumented with two or three detectors will, in addition, yield an accurate measurement of queue, and accuracy will be less sensitive to the effects of the unpredictable traffic events enumerated above. In the final analysis, the number of detectors to utilize in a lane will depend on the traffic and geometric characteristics, and the type of control that is to be implemented at the associated intersection.

3.2.5 COMMUNICATIONS SYSTEM DESIGN

A. General Considerations

The function of the communications system is to provide data links between the central computer and field equipment. It may also provide a link between computers if a multiple-processor configuration is selected for the traffic control system. The bulk of the data communications is concerned with surface street traffic sensing and intersection control and consists of:

- Transmission of control commands from the computer to the intersection controllers
- Transmission of vehicle sensor signals and controller status signals to the computer.

Other functions of the traffic control system may have data communication requirements such as:

- Transmission of ramp metering commands to freeway ramp controllers and controller status signals back to the computer

- Transmission of message commands from the computer or control panel to variable message signs, and acknowledge signals from the signs to the computer

- Transmission of data from special vehicle (bus and emergency vehicle) sensors to the computer.

The vehicle detector relays are actuated at a maximum rate of one on-off cycle per second. Time between relay turn-on and turn-off must be established in the computer to within about 0.02 second on the average, either by sampling more often than 20* times per second or by some other method. The absolute time at which relay turn-on and turn-off occurs must be established to within 1 second.

A communications system designed to meet these requirements consists of data transmitters and receivers and the interconnecting medium. The options that are theoretically available in designing the system are listed below.

- Type of Interconnect
  - Radio
  - Telephone cable (voice grade or telegraph grade)
  - Coaxial cable
  - Microwave transmission
- Communications Technique
  - DC Relay
  - DC Multiplex
  - Time Division Multiplex (TDM)
  - Frequency Division Multiplex (FDM)

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*The rms error due to sampling is given by $T/\sqrt{6}$, where T is the sampling period. For this case the maximum sampling period is $T = .02\sqrt{6}$ or .049 second. The sampling rate must therefore be greater than 20 per second.

- Cable Alternatives
  - Leased or owned.

The communications design results from tradeoffs among these alternatives and combinations of these alternatives. The major tradeoff considerations are:

- Functional adequacy
- Acquisition cost
- Operating cost
- Reliability and maintainability.

The design tradeoffs are discussed in the following paragraphs.

Radio interconnects of the type generally used for control of MC systems and synchronization of other interconnected controllers are unsuitable for central computer systems. Radio transmission is subject to problems with noise and interference. In urban areas radio propagation problems (reflections) are another limiting factor. Frequency allocation is a problem because of the large number of channels required.

Telephone cable is the practical way of linking the field equipment to the computer or to a central data connecting point. The cable may be leased (in wire pairs) or owned. Leased cable may be either voice-grade or telegraph-grade. Voice-grade cable has a guaranteed bandwidth from 300 to 3000 Hz and is the type required for either the TDM or FDM multiplexing techniques. Telegraph-grade cable can be leased with guaranteed bandwidths of from 0 to 30 or 75 Hz and is suitable for either DC relay or DC multiplex transmission.

If the geographical distribution of field equipment permits, it is sometimes possible to collect data at an intermediate point by means of telephone lines for transmission to the computer over a single microwave channel. Provided enough data can be collected and the distance to the central control facility is far enough, this approach may result in lower costs for acquisition and operation of the system interconnect.

Another possible requirement for a high capacity link may arise if the central control facility is moved to another location some time after the complete system has been installed. In this event, the alternatives are to reroute the cable interconnect system to the new location, or to transmit data en masse between the old and new sites by either a microwave link or coaxial cable. The first alternative is more costly if the interconnect system is owned rather than leased. Leased lines can be transferred with new termination charges. In either case, a single microwave link or a coaxial cable (which may also be leased or owned) may be competitive.

B. Communication Techniques

The paragraphs following describe some of the communications techniques that can be employed to implement the system.

(1) DC Relay

DC Relay (DCR) communications employs relays at both ends of a DC path. Standard voice-grade leased service cannot be utilized for this service because DC paths are not guaranteed. The input data are introduced by means of relay driver amplifiers and the output are contact closures.

The main advantage of DCR communications is the low cost and simplicity of the terminal equipment. However, this is usually more than made up for by high cable costs. At least two pairs are required for each controller and one for each sensor. As a result this technique is limited to situations where owned cable can be installed cheaply and where the distances from the central location are short (up to 3 or 4 miles). Because of the heavy cabling requirements, it is also difficult to provide for expansion.

(2) DC Multiplex

DC Multiplex (DCM) communications employs relays in combination such that at least three functions appear on a single pair. Each controller thus requires one pair, compared to two for DCR. However, each sensor still requires one pair. One method of accomplishing the multiplexing, which is illustrated in Figure 3-5, makes use of voltage

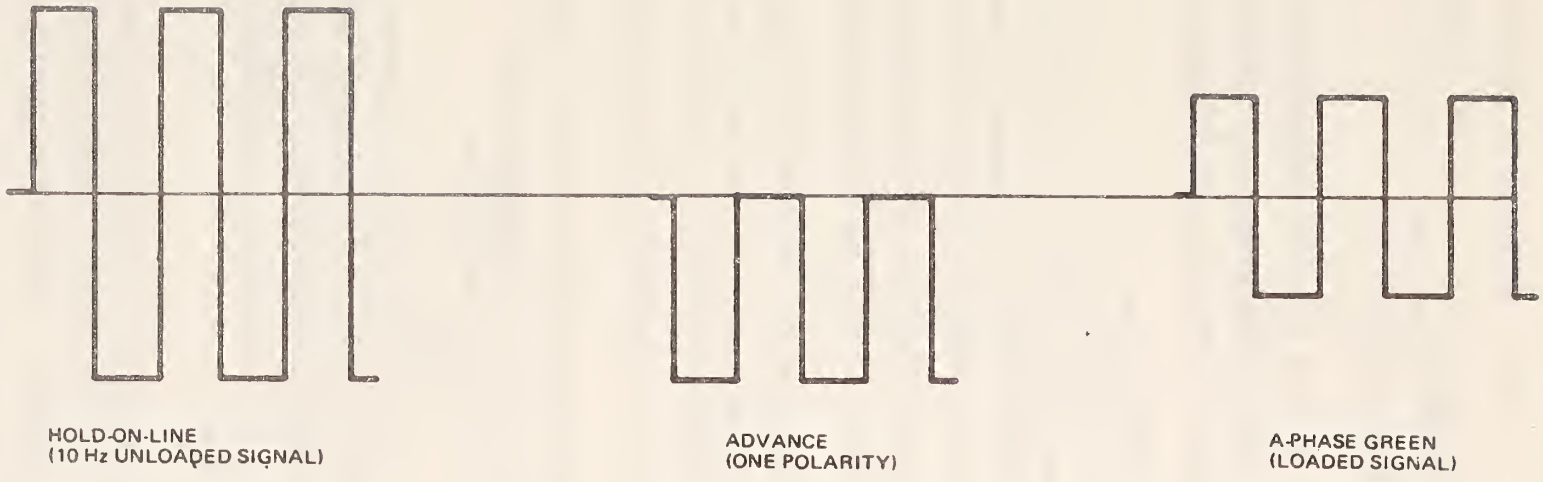

Figure 3-5. DC Multiplex Transmission

latching or polarity sensing relays coupled to choppers. The hold on-line signal which imposes computer control on either a pre-timed or actuated controller is a 10-Hz square wave, while the advance signal (or yield in the case of an actuated controller) is one polarity of the square wave. The controller indicates that it is in A-phase green by loading the hold signal which is sensed at the other end of the line.

Cable costs, although less than with simple DCR, are still high. Equipment cost is higher than with DCR but is still relatively low. This technique has been used successfully where it has been possible to negotiate a favorable telegraph-grade tariff.

(3) Time Division Multiplex

Time Division Multiplex (TDM) is one method of voice-band multiplexing applicable to traffic control systems, the other being frequency-division multiplexing. With this technique, the entire voice band is treated as a single high speed channel. With a bandwidth from 300 to 3000 Hz, a data transmission rate of up to 1200 bits per second can be accommodated on a pair of wires. There are three different types of TDM communications, as follows:

- The periodic-sampling TDM system consists of a scanning device which repetitively samples a large number of sending units in sequence at rates up to 1,200 samples per second, and which is connected by means of a single pair of wires to a receiver synchronized with the scanner.

- The change-of-state TDM technique is similar to periodic-sampling TDM except that a binary code sequence unique to each sending device is transmitted only when the device changes state.

- Compressed data TDM is similar to periodic sampling TDM except that the data representing a quantity being measured, such as occupancy or vehicle count, are accumulated in digital circuitry until interrogated by a master timing unit, at which time a binary code sequence representing the accumulated value is transmitted.

Periodic sampling TDM is illustrated in Figure 3-6, which shows a two-way system. The pulse train that is formed by the action of the sampler is transmitted on a pair of wires by an AM or FM transmitter. The position in time of each bit in the pulse train identifies the source of the data.

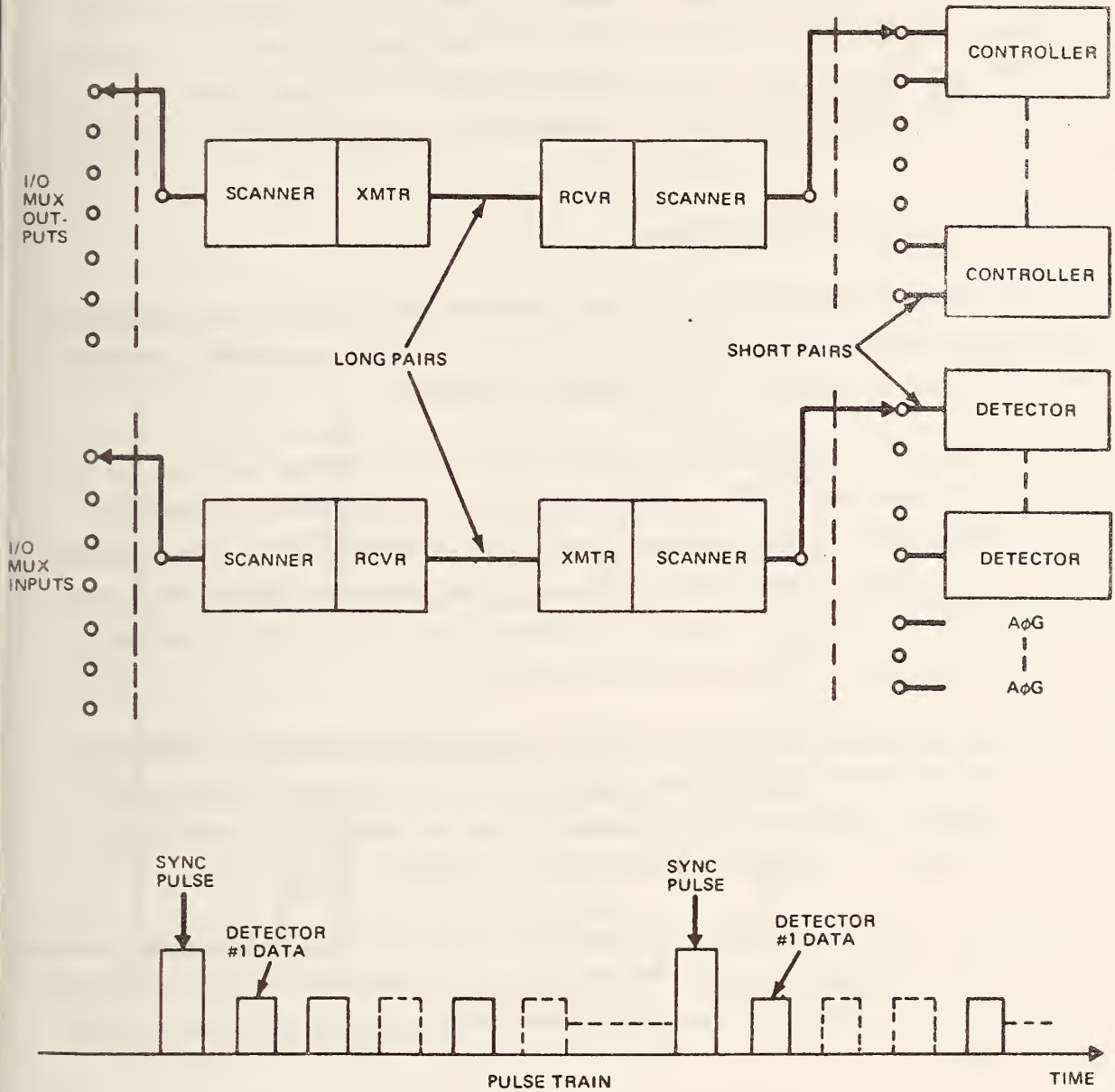

Figure 3-6. Time Division Multiplex Transmission

TDM is most applicable where the field equipment to be controlled or sampled is clustered together. If it is not, then the costs of the cabling required to bring the data to a sampling point can become excessive. A factor that can increase costs further is that some telephone companies have minimum leasing rates for these relatively short lengths of cable. TDM equipment is more complex than other types and has been more costly. Recent improvements in design and production techniques have made them more competitive, however.

(4) Frequency Division Multiplex

Frequency Division Multiplex (FDM) is another method of voice-band multiplexing. With this technique the voice band is divided into about 20 channels, each with a bandwidth of 120 Hz. There are three types of FDM systems, as follows:

- Amplitude-modulated FDM consists of tone transmitters, each generating a different tone within the audio band from 300 to 3000 Hz, and feeding a single pair of wires that connects all of the transmitters to a corresponding set of tuned audio receivers. Typically, the presence of a tone represents the "on" state of the device, and absence of the tone represents the "off" state of the device.

- Two-frequency-shift FDM is identical to amplitude-modulated FDM except that two tones instead of one are used by each transmitter/receiver pair. Typically, one tone (mark) represents the "on" state of the device being monitored, and the second tone (space) represents the "off" state.

- Three-frequency-shift FDM technique is similar to the two-frequency technique except that logic circuits at the transmitter and receiver permit transmitting the on-off states of two sending devices using a single transmitter/receiver pair.

A two-way FDM system is shown in Figure 3-7. FDM equipment is widely used, is reliable, and is of moderate cost. It is applicable to any intersection configuration, and is easily expanded to handle additional controllers and sensors.

C. Cable Alternatives

The alternative means of obtaining the interconnecting cable for the traffic control system are:

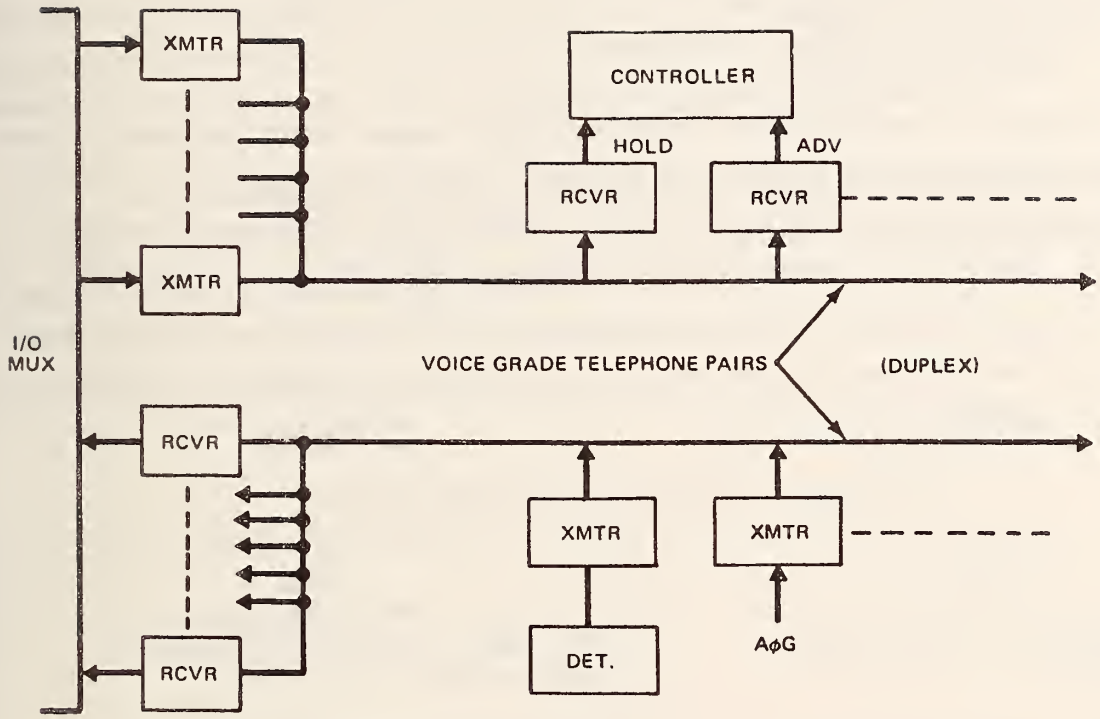

Figure 3-7. Frequency Division Multiplex Transmission

- The cable can be leased from the telephone company, which maintains the cable and charges a fixed monthly rate
- The cable can be installed and maintained on a proprietary basis.

The major factors to be considered in evaluating these alternatives are cost, expansibility and reliability of operation.

Cost tradeoffs between the leased/owned cable alternatives are required in order to determine the optimum system configuration. Among the alternatives are:

- FDM/leased cable
- FDM/owned cable
- TDM/leased cable
- TDM/owned cable.

Factors which must be considered are: local wire costs, number of intersections and sensors, number of commands to controllers, number of returns from controllers, relative locations of control and controlled areas, local ordinances (e.g. underground vs. pole installations), availability of existing ducts or poles, type of roadway surfaces, etc.

Typical costs associated with the cable and its installation are shown in Table 3-2. The costs will vary depending on rates of local contractors, telephone companies, and local design conditions.

TABLE 3-2. MAJOR SIGNAL WIRE COSTS

Item	Cost
Furnish and install conduit in roadway	$3 - $25/ft. (depending on surface composition)
Resurface installation site	$1 - $3/ft.^{2} (depending on surface composition)
Furnish and install twisted shielded pair in conduit	$0.75 - $4 (depending on number of twisted pair)
Rental of telephone company lines	$2.0/quarter mile/2 pair/month
Termination cost for telephone company lines	$9 - $15/2 pair/each end (depending on local design conditions)
Cable maintenance	$.065/mo./ft.

3.3 UTCS STREET INSTALLATION DESIGN

3.3.1 UTCS SECTIONAL AND INTERSECTION BREAKDOWN

The UTCS test area includes 111 controlled intersections in the area of Washington, D. C. shown in Figure 3-8. Based on analyses of traffic data and site surveys, the area was divided into four sections. It includes two arterials: Wisconsin Avenue from Porter Street to M Street, and M street from Key Bridge to 28 Street; a high-density grid north of Pennsylvania Avenue to L Street, and a low density grid from Pennsylvania Avenue south to Constitution Avenue. Forty-eight CIC intersections are dispersed with-within the complex, as indicated in Figure 3-8. A summary of the controlled intersections, by section, giving location, whether detectorized lanes are included, and whether the intersection is instrumented for CIC operation, is presented in Table 3-3.

Four intersections located on the periphery of the UTCS complex have been instrumented with early warning detectors. A total of 12 detectors has been installed, distributed among the intersections as follows:

INTERSECTION	NO. OF DETECTORS
K and 10 St.	2
Independ. and 14 St.	4
Mass. and 22 St.	3
Rhode Is. and 17 St.	3

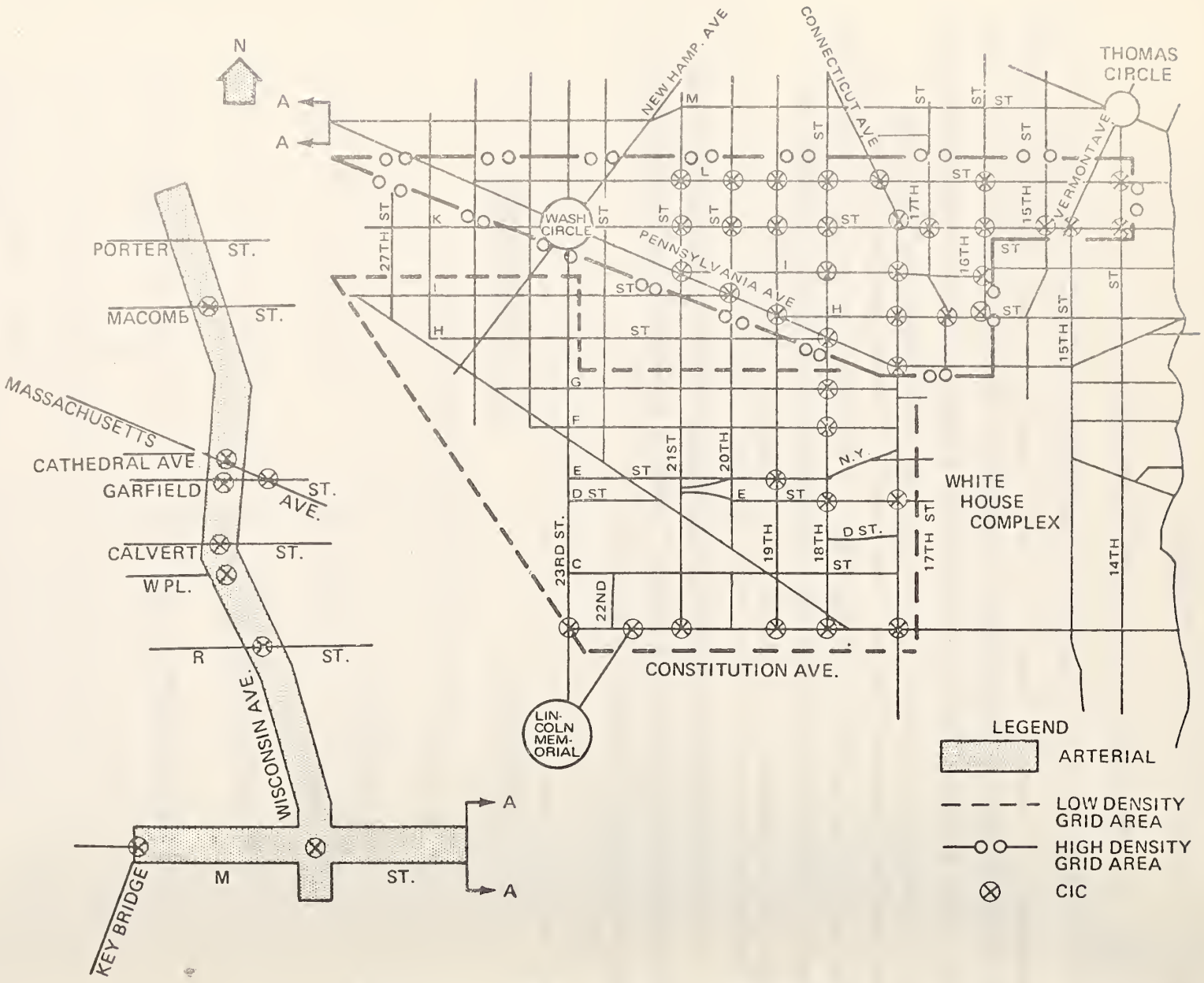

Figure 3-8. Test Area Street Classification

TABLE 3-3. UTCS CONTROLLED INTERSECTIONS SUMMARY

Section	Intersection	Detector Instrumented	CIC Instrumented
1	Penn./28/M	X	
	M/29	X	
(M St.	M/30		
Arterial)	M/31	X	
	M/33		
	M/34		
	M/Wisc.	X	X
	M/36		
	M/Key Br.	X	X
Totals	9	5	2
2	Wisc./Whitehaven		
	Wisc./34		
	Wisc./Porter		
(Wisc. Ave.	Wisc./Newark		
Arterial)	Wisc./Edmunds		
	Wisc/Woodley		
	Wisc./Mass.	X	X
	Wisc./Garfield	X	X
	Mass./Garfield	X	X
	Wisc./R	X	X
	Q/33		
	Wisc./N		
	Wisc./O		
	Wisc./P		
	Wisc./Q		
	Wisc./Macomb	X	X
	Wisc./Calvert	X	X
	Wisc./Hall		
	Wisc./W	X	X
Totals	19	7	7

TABLE 3-3. UTCS CONTROLLED INTERSECTIONS SUMMARY (Cont.)

Section	Intersection	Detector Instrumented	CIC Instrumented
3 (Grid North of Penn.)	Penn/26/L	X	
	Penn/25/L	X	
	Penn/24/K	X	
	K/25		
	Wash Cir. SW		
	Wash Cir. NE		
	Penn./18/H	X	X
	Penn./17	X	X
	Penn./Jackson	X	
	K/19	X	X
	K/18	X	X *
	K/Conn./17	X	X
	I/20		
	I/19	X	
	I/18	X	X *
	I/17	X	X *
	Penn./19/H	X	X
	H/18	X	
	H/17	X	X
	Penn./I/20	X	X
	Penn./I/21	X	X
	Penn./22	X	
	K/21	X	X
	K/20	X	X
	L/23	X	
	L/22/N.H.	X	
	L/21	X	X
	L/20	X	X
	L/17	X	
	L/16	X	X
	L/15	X	
	L/19	X	X

TABLE 3-3. UTCS CONTROLLED INTERSECTIONS SUMMARY (Cont.)

Section	Intersection	Detector Instrumented	CIC Instrumented
3 (Cont.)	L/18	X	X
	L/Conn.	X	X*
	K/17	X	X
	K/16	X	X
	K/15	X	X
	I/17/Conn.	X	
	I/16	X	X
	H/Conn./Jackson	X	X
	H/16	X	X
	L/Vt.	X	
	L/14	X	X
	K/14	X	X
	K/15/Vt.	X	X
Totals	45	41	28
4 (Grid South of Penn.)	E(N)/23		
	C/23		
	C/21		
	Const./23	X	X
	Const./22	X	
	Const./21	X	X
	Va./E		
	Va./21		
	Va./20		
	Va./19/C	X	
	Va./18		
	Const./20	X	
	Const./19	X	X
	Const./18	X	X
	Const./17	X	X
	E(N)/20	X	
	E(N)/21	X	
	E(N)/19	X	X

TABLE 3-3. UTCS CONTROLLED INTERSECTIONS SUMMARY (Cont.)

Section	Intersection	Detector Instrumented	CIC Instrumented
4 (Cont.)	N.Y./18	X	
	E(S)/20	X	
	E(S)/19	X	
	E(S)/18	X	X
	Const./HB	X	X
	F/17	X	
	N.Y./17	X	
	E(S)/17	X	X
	G/18	X	X
	17/Exec.	X	
	Va./23		
	G/23		
	G/22		
	I/23		
	H/23		
	F/18	X	X
	F/20		
	G/19		
	G/20		
	G/21	X	
Totals	38	23	11
System Totals 111		76	48

*Intersections are currently inoperative as CIC due to subway construction.

3.3.2 UTCS CONTROLLERS

The UTCS controls a total of 111 controllers in its present configuration, including 107 pre-timed and 4 semi-actuated controller. The pre-timed controllers include 40-circuit and 19-circuit types, and normally operate with as few as 4 and as many as 16 intervals over a cycle. Both the pre-timed and semi-actuated types operate on a 3-dial system: Dial 1 (basic), Dial 2 (AM peak), and Dial 3 (PM peak), which provide offset, split, and cycle changes (just offset in the case of semi-actuated) on a time-of-day basis. The appropriate dial is selected by a signal transmitted by radio which ties in with the District's master clock. Controller cycle lengths and offsets are also synchronized and coordinated in terms of the District's master clock by means of the radio link. The three-dial system thus provides a coordinated, time-of-day responsive, back-up system for the UTCS.

3.3.3 UTCS DETECTOR SELECTION

Based on surveys, test results, and tradeoff studies, the loop detector was selected for application in the UTCS complex. The following paragraphs summarize the results which led to the final selection.

The normally overhead-mounted ultrasonic and radar detectors were excluded from consideration because the Fine Arts Commission of the District of Columbia prohibits permanently installed devices requiring mast arms greater than six feet in length. The sonic detector mounted in a side fire configuration (on a curbside pole) could not be used because it cannot observe a uniquely identifiable lane.

From these factors it was concluded that only magnetic or inductive loop detectors remained as UTCS candidates. In choosing between magnetic and loop detectors the major factor is the inherent measurement accuracy obtainable from the unit. The quantitative accuracy of the magnetic detector is not as high as that of the loop detector due to the somewhat ill-defined and variable character of its sensitive field. The characteristics of the loop detector are expected to be satisfactory, and therefore the loop detector was selected for use in the UTCS test site.

A. Error Guidelines

Accurate instrumentation is required in order to develop measures of effectiveness and evaluate experiments. This requirement is somewhat simplified by separating the

system's errors into a bias and a random component. Although the bias component may limit the absolute accuracy with which MOE's may be obtained, it does not necessarily limit the comparison of one control technique with another.

Reduction of the random component of error is ultimately limited by statistical variations in traffic behavior. Analysis has shown that errors in volume of 8% to 15%, and errors in speed of 6%, are typical. Another significant limitation in reducing the random component of error depends on how closely the experiment can match demand and other conditions. In practice, an experiment is generally run for a fairly long period of time, so that short-term variations in demand, weather, temporary obstructions, etc. are averaged.

For these reasons it appears that detector accuracy in the range of 5% to 8% (one standard deviation) is probably sufficient.

B. Detector Design Considerations

To determine whether the loop detector could satisfy above requirements or whether instrument modifications or special approaches to installation or use were required. The following steps were taken:

- A survey was made of the open technical literature and manufacturer's literature.
- Survey sheets were sent to various using agencies to determine their experience.
- Consultations were held with manufacturers.
- Consultations were held with certain sophisticated users.

The end objectives of this effort were to enable a procurement specification for the detectors to be prepared and an error analysis to be prepared. The information obtained is summarized as follows:

- Loop sizes of less than 6 ft. x 6 ft. are subject to double count problems on high-bed vehicles. It appears that accurate detection height may range from 60% to 100% of the shortest dimension of the loop.

- Some tailgating count errors may be developed for detectors with long dropout time.

- If relays are used for the output they sould be mercury wetted to ensure long life and to prevent contact bounce problems during computer interrogation.

- No adjacent-lane interference had been encountered on loops of 6 ft. width, on roadways as narrow as 10.5 ft.

- The non-crystal-controlled type of unit appears to be more subject to the effects of components drift with time and temperature. Furthermore, some observers have noted mutual interference where the loops or electronics of two or more detectors were in close proximity.

- When ambient temperatures are above 90°F some erratic operation has been encountered.

The investigations also generally indicated that a counting error of considerably under 5% is to be anticipated. Tests run by the Port of New York Authority also indicated that accuracies of this order might be anticipated for occupancy, but no really substantiated data existed. Furthermore, the environment under which these tests were conducted is relatively benign.

In order to determine the unknown components of detector error and to ensure compatibility between the detector capability and the system requirements, a test program was undertaken during the UTCS study phase. A summary of its results is given below.

C. Summary of Detector Test Program Results

The detector test program consisted of an examination of circuits, temperature tests, phase shift measurements, and dynamic vehicle testing on an outdoor track. For purposes of the test program, three production units from each of three detector manufacturers (labeled A, B, and C in the following discussion) were obtained. It was found that performance varied widely from manufacturer to manufacturer in both the static temperature testing and the vehicle testing.

(1) Examination of Circuits

Only manufacturer B had temperature-stabilizing circuits. Manufacturer A had filters with time constants significantly longer than the other two. Otherwise the circuit designs of all three were essentially the same.

(2) Temperature Tests

Manufacturers B and C performed properly within the UTCS temperature range; manufacturer A, while meeting own temperature specifications (less severe than UTCS requirements) performed erratically at the ends of the UTCS range.

(3) Phase Shift Measurements

The gain of the phase detector portion of the circuit (voltage output vs. phase shift input) for both manufacturer A and B was essentially the same, while for manufacturer C it was higher. This is an important consideration because the gain affects the capability to detect high-bed trucks in their entirety and to detect two vehicles with short headways.

(4) Vehicle Testing

Errors in occupancy are caused by variation in vehicle type, variations between electronics of the same manufacturer, and variation among the physical loops. These variations are listed in Table 3-4.

Note: components of detector error from sources available prior to the detector test program are underlined and data from the test program are not underlined.

Table 3-5 shows the data statistically combined and summarized. Although over 1000 vehicle runs were performed during the test program, the construction of tests to isolate the individual error contributions constrained each individual test to a limited number of runs. Thus, the statistical samples involved in each test are limited, and the results must be considered to indicate only general tendencies of the detector performance.

The results of the test program as interpreted by the error analysis indicate that the performance of the better detectors is generally close to the accuracy guidelines defined above. The loop detector, therefore, is considered to be capable of satisfying the

TABLE 3-4. DETECTOR ERRORS

A. Variation in Vehicle Detected Position	Bias Effect (St. Dev.)	Random Effect (St. Dev.)
From unit to unit	0.51 ft	
Over vehicle mix	0.55 ft 0.67 ft	
Due to non-center-of-lane condition		0.57 ft
Due to vehicle bounce		0.37 ft
With repetitive observations		0.64 ft
With loop installation	0.54 ft	
B. Variation in Internal Time Differences		
With temperature	5 msec	
From unit to unit	5 msec	
With repetitive observations		18 msec
With periodic sampling		13 msec
With loop installation	45 msec	7 msec
Over vehicle mix		22 msec
Due to communications equipment		7 msec

TABLE 3-5. RELATIVE PRESENCE ERROR SUMMARY

	Bias		Random	
	20 ft/sec (St. Dev.)	40 ft/sec (St. Dev.)	20 ft/sec (St. Dev.)	40 ft/sec (St. Dev.)
Spatial Measurement Error*	.047	.047	.037	.037
Time Difference Error	.044	.085	.020	.048
Total Standard Dev.	.064	.097	.042	.055

*Includes statistical addition of a 0.5 ft. bias error each for the time and temperature errors in part A of Table 3-4. Also includes statistical addition of a 30 msec bias error for the time error in part B of Table 3-4.

system surveillance requirement. It is strongly emphasized, however, that this statement will not apply to every manufacturer's equipment. Furthermore, this capability may be compromised by long lead wires or by improper installation and adjustment procedures.

3.3.4 UTCS DETECTOR ALLOCATIONS

UTCS detectors were located on selected lanes in accordance with the guidelines enumerated in paragraph 3.2.4. Lanes were instrumented with a single detector for the measurement of volume, speed, and occupancy. Lanes at critical intersections were instrumented with two or three detectors depending on the block length.

Multi-detector lanes provide a more precise measurement of queue length than that possible with a single detector. Queue length is an important variable from the point of view of both control strategies and measures of effectiveness. For example, the UTCS controls split on a cycle-by-cycle basis so as to make critical queues proportional to respective block lengths; in this way all available vehicle storage is used as efficiently as possible, and the probability of intersection blockage is minimized. Multi-detector instrumentation provides a more precise measurement of stops and delay related to the queue measurement. In addition, multi-detector instrumentation provides better average volume, speed, and occupancy values for the lane.

The distance of detectors from the intersection was determined as follows:

- The placement of detectors in lanes which are instrumented for queue length is strongly influenced by the error characteristics of the queue length algorithm techniques. As the second (upstream) detector is moved closer to the first detector the estimate becomes more accurate but the measurable queue becomes shorter.

- A distance of 175 feet between detectors and 35 feet between the stop line and the first detector was chosen to achieve good accuracy and good lane coverage (Figure 3-9). Long links which are also subject to long queues are instrumented with a third detector at a distance of 60-200 feet from the second detector depending on the block length. In the majority of cases in UTCS the distance is 155 feet.

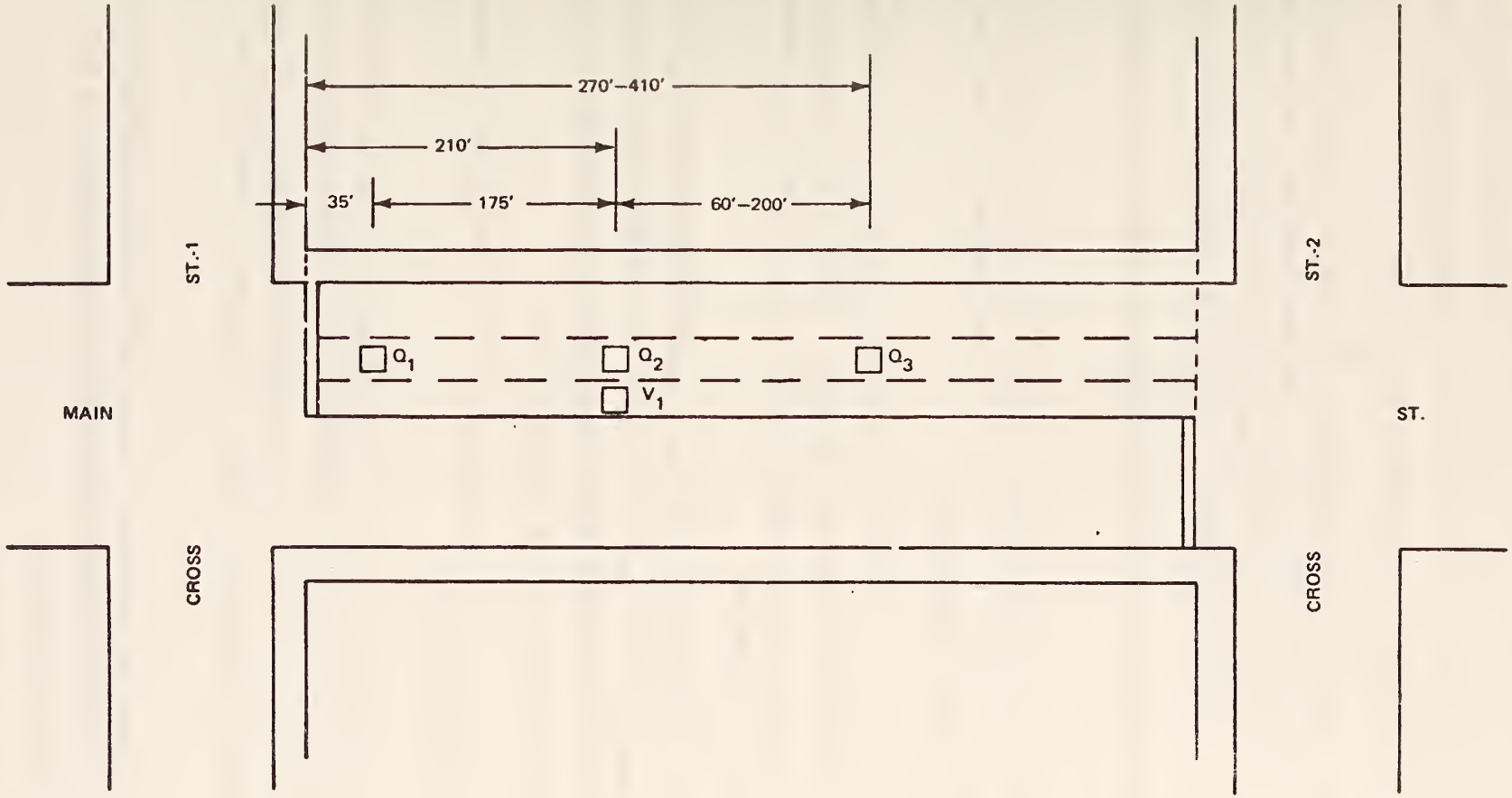

Figure 3-9. Detector Placement

- Where a lane to be instrumented is adjacent to a lane instrumented for queue measurement, the detector is to be located 210 feet from the stop line, thus siting it next to the second detector in the queue-measured lane. Thus a comparison of speed and occupancy can be readily made.

- Where a lane is to be instrumented and no queue-instrumented lanes are present on that link, it is desirable to make measurements in an area which is generally representative of free flow or at least average flow conditions, thus implying a mid-block location or a location at some distance from the intersection.

The ground rules for detector placement were modified by the following considerations:

- Queue detectors were not placed in lanes which change direction as a function of time (e.g. M St., 17 St.) as the problems implicit in the software structure require special consideration.

- Where closely spaced "H" type intersections exist (Figure 3-10) detectors were placed on the outer legs, as shown. This was done to permit a reasonable estimate of queue measurement and to obtain good measurement of overall flow conditions.

- Although parking garages are major sources and sinks, they have not been instrumented with detectors in this plan as problems involving detector placement, direction sensing, legal complications, and directional and lane assignment of existing flow require special study.

- The specific positions recommended must be modified where obstructions such as manholes exist.

With all of these factors in mind, traffic data for each link and intersection were reviewed and on-site observations and studies were made. This resulted in a classification of the links as shown in Figure 3-8 and the generation of specific detector locations. Reference 3A describes these specific locations and indicates the basis for the placement of each detector.

Table 3-6 provides a summary of some statistical data regarding the detector placements. Figure 3-11a illustrates a typical UTCS loop installation and Figure 3-11b illustrates the loop slot construction.

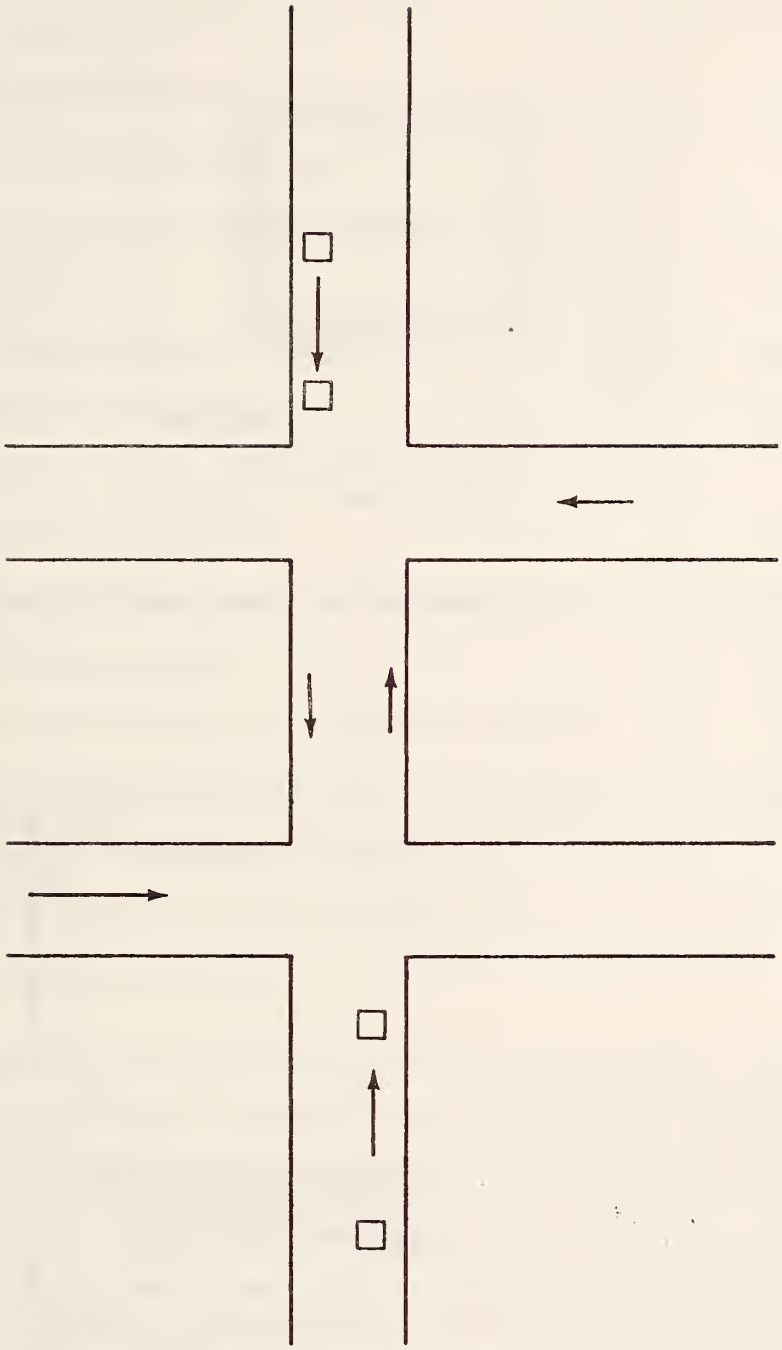

Figure 3-10. H-Intersection Detector Placement

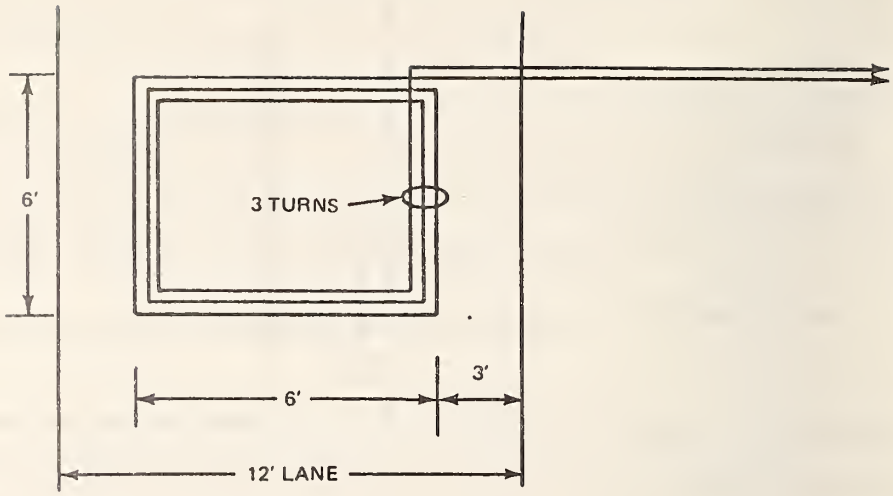

Figure 3-11a. Typical UTCS Installation of Single Lane Vehicle Loop

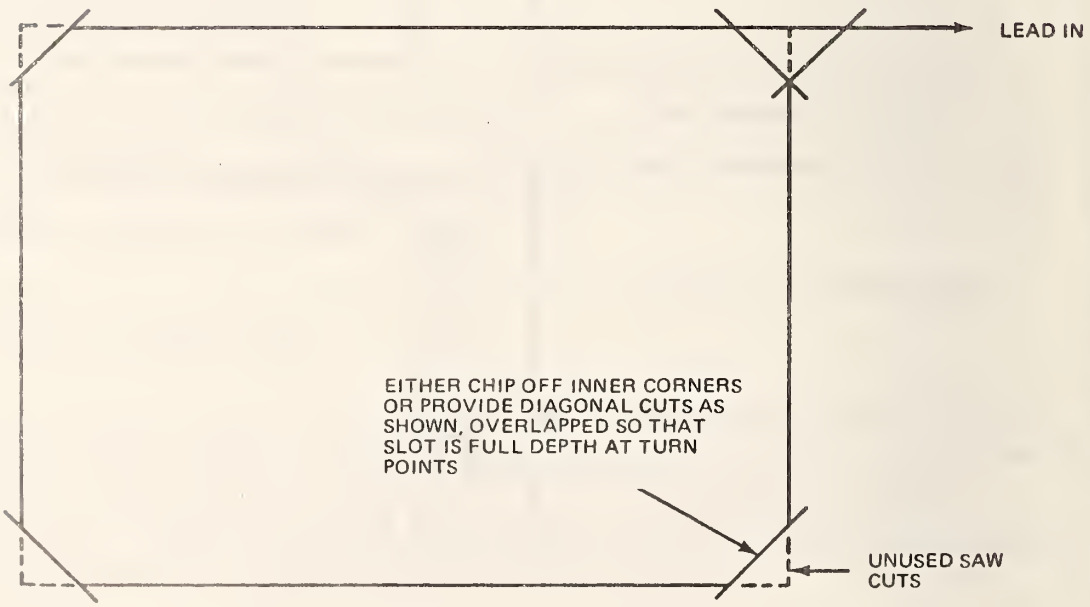
LEAD IN
EITHER CHIP OFF INNER CORNERS OR PROVIDE DIAGONAL CUTS AS SHOWN, OVERLAPPED SO THAT SLOT IS FULL DEPTH AT TURN POINTS
UNUSED SAW CUTS

Figure 3-11b. UTCS Vehicle Loop Slot Construction

TABLE 3-6. UTCS DETECTOR PLACEMENT STATISTICS

Item	Quantity
Signal controlled intersections	111
Controllers	111
Total detector instrumented intersections	80
Instrumented intersections not in test area (early warning)	4
Approaches in test area	385
Total instrumented links (12 early warning links)	265
Total instrumented links in test area	251
Critical intersections instrumented for queue length	48
Links instrumented for queue length	138
Links instrumented for volume, speed and occupancy only	127
Total number of vehicle detectors	497
Average number of detectors per instrumented intersection	6.2
Average number of detectors per controller	4.5
Lanes instrumented for queue length (2 detectors)	44
Lanes instrumented for queue length (3 detectors)	94

3.3.5 UTCS COMMUNICATIONS

Tradeoff studies were conducted for various combinations of communication techniques, in conjunction with owned and leased telephone lines, during the study phase of the UTCS program (Reference 3B). These are summarized in Table 3-7.

The tradeoff studies clearly indicated cost advantages for the FDM/leased line combination. The final selection consisted of a combination 2FS/3FS-FDM communications technique in conjunction with leased telephone lines. The 2FS technique is used for transmitting all vehicle detector actuations and controller A, B and C-phase green returns to central. The 3FS technique is used for transmitting the hold and advance

TABLE 3-7. UTCS COMMUNICATIONS TRADEOFF SUMMARY

Tel. Lines	Detector Communication	Controller Communication
Dist. Owned	2FS-FDM	Polar D.C.
Dist. Owned	AM-FDM	AM-FDM
Dist. Owned	3FS-FDM	3FS-FDM
Leased	2FS-FDM	Polar D.C.
Leased	AM-FDM	AM-FDM
Leased	2FS-FDM	2FS-FDM
Leased	3FS-FDM	3FS-FDM
Leased	PS-TDM	PS-TDM
Leased	CS-TDM	PS-TDM

commands from central to the controllers and actuations from bus detectors to central. A summary of the interface relationships of the various signals with central communications is given in Table 3-8.

The UTCS/BPS uses a total of 79 telephone pairs, 55 input lines and 24 output lines. The input lines include the return signals from 144 bus detectors which have been integrated with the UTCS. A breakdown of signal types, number transmitted, and the total number of transmitter and receiver modules used by UTCS communications is given in Table 3-9.

TABLE 3-8. SUMMARY OF TELEPHONE LINES/CENTRAL COMMUNICATIONS/CIU INTERFACE

Signal Type	Communication Module Type	Remarks
Vehicle Detector	2-Frequency Receiver	A frequency (f_s) on incoming line indicates no presence at detector, whereas a carrier shifted to f_m indicates presence. The on-off state of the associated discrete output line to the CIU is affected accordingly.

TABLE 3-8. SUMMARY OF TELEPHONE LINES/CENTRAL COMMUNICATIONS/ CIU INTERFACE (Cont.)

Signal Type	Communication Module Type	Remarks
Bus Detector	3-Frequency Receiver	A frequency (f_m) on the incoming line indicates a Stop Bus. The on-off state of the Bus Stop (BS) discrete output line to the CIU is affected accordingly. A frequency (f_o), (f_m), or (f_s) on the incoming line indicates carrier is normal. The on-off state of the Bus Error (BE) discrete output line to the CIU is affected accordingly. A frequency (f_s) on the incoming line indicates a Thru Bus. The on-off state of the Bus Thru (BT) discrete output line to the CIU is affected accordingly.
A-Phase Green Return	2-Frequency Receiver	Same as vehicle detector except that presence refers to A-phase green signal.
Hold-Advance Commands	3-Frequency Transmitter	A logic 1 from the CIU hold line will output a carrier at frequency (f_o) to the associated controller telephone pair. A logic 1 from the CIU advance line will output a frequency (f_m) to the associated controller telephone pair. A "test" logic 1 to the (f_s) input of transmitter will set up a test of controller communications. (Reference 6C).

A. UTCS Signal Allocations

UTCS telephone lines (voice grade) theoretically provide a maximum of 20 frequency channels per line. In the UTCS, the number of signals allocated to an incoming line has been conservatively limited to a maximum of seventeen. In some instances, input lines are not operating at the 17-channel limit. The extreme case, which includes signals at Washington Circle SW, Washington NE, and Pennsylvania and 24 St., uses a total of only eight channels on the associated line. The use of lines at less than capacity in these instances was dictated by geometric considerations which involved a tradeoff between installation costs versus the additional cost of the lines.

The UTCS outgoing lines are conservatively limited to five channels per line. This limitation was imposed to permit the transmission of the controller hold and advance signals at a higher power level and, therefore, with a higher reliability. The theoretical twenty channels per line can be attained on the outgoing lines by transmitting signals at a lower power level. However, to achieve comparable reliability, conditioning amplifiers would have to be provided by the telephone company with an attendant higher leasing cost, or individual conditioning amplifiers would have to be provided at each controller.

TABLE 3-9. BREAKDOWN OF UTCS COMMUNICATIONS SIGNALS AND MODULES

Signal	No. of Signals	No. of Modules
A-phase green	111	Total of 630, 2-FS receivers and transmitters
B-phase green	21 *	
C-phase green	1 *	
Vehicle detectors	497	
Bus detectors	144	Total of 255, 3-FS receivers and transmitters
Hold	111 **	
Advance	111 **	

*These signals are used in conjunction with the map display only.
**Hold and advance signals are combined in each unit.

B. Detector Electronics Frequency Allocations

The tuned circuits used in the UTCS vehicle detector circuits are crystal-controlled in the range 80-130 kHz. The crystal frequency is selectable in steps of 2.5 kHz. In order to limit the possibility of any cross-coupling between adjacent detector units in a controller cabinet, the operating frequencies for the complement of detectors were selected for maximum separation between units. For example, the five detectors included in the controller cabinet at G and 18th Streets were allocated frequencies of 80, 92.5, 105, 117.5 and 130 kHz, or a separation of 12.5 kHz between detectors.

3.3.6 UTCS STREET INSTALLATION

The present UTCS street installation consists of a network of 111 controllers, 497 vehicle detectors, 144 bus detectors, 116 field cabinets, 36 electronics cabinets, splice boxes, and telephone terminals.

UTCS street installation drawings (Reference 3C) provide the detailed plans for installing the street equipment, including dimensions for locating detectors, pad-mounted cabinets (CB's) and pole-mounted cabinets (EB's). The detailed locations of splice boxes are shown, as well as the relative location of new and existing manholes used in routing conduit to interconnect the required signals to the appropriate telephone company line terminals. Figure 3-12 shows a section of sheet 12 of Reference 3C, which provides the installation details centered at Constitution Ave. and 17 Street. Appendix F presents sample sheets of UTCS/BPS reference documents which describe the installation. Figure 3-13 shows a typical UTCS controller cabinet installation. Shelves are labeled so that the cabinet equipment complement can be properly referenced. The lower three shelves accept communications modules as required, and the upper four shelves accept vehicle and bus detector electronics modules.

There are 116 pad-mounted controller cabinets in the present UTCS configuration. Of these, 107 contain pre-timed controllers with adapter units, communications and detector electronics modules; 4 contain semi-actuated controllers with adapter units, communications and detector electronics; and 4 are located in the outskirts of the controlled area, containing detector electronics and communications associated with early warning detectors. In addition to the controller cabinets, 36 pole-mounted cabinets (EB's) are used to contain additional electronics and communications modules.

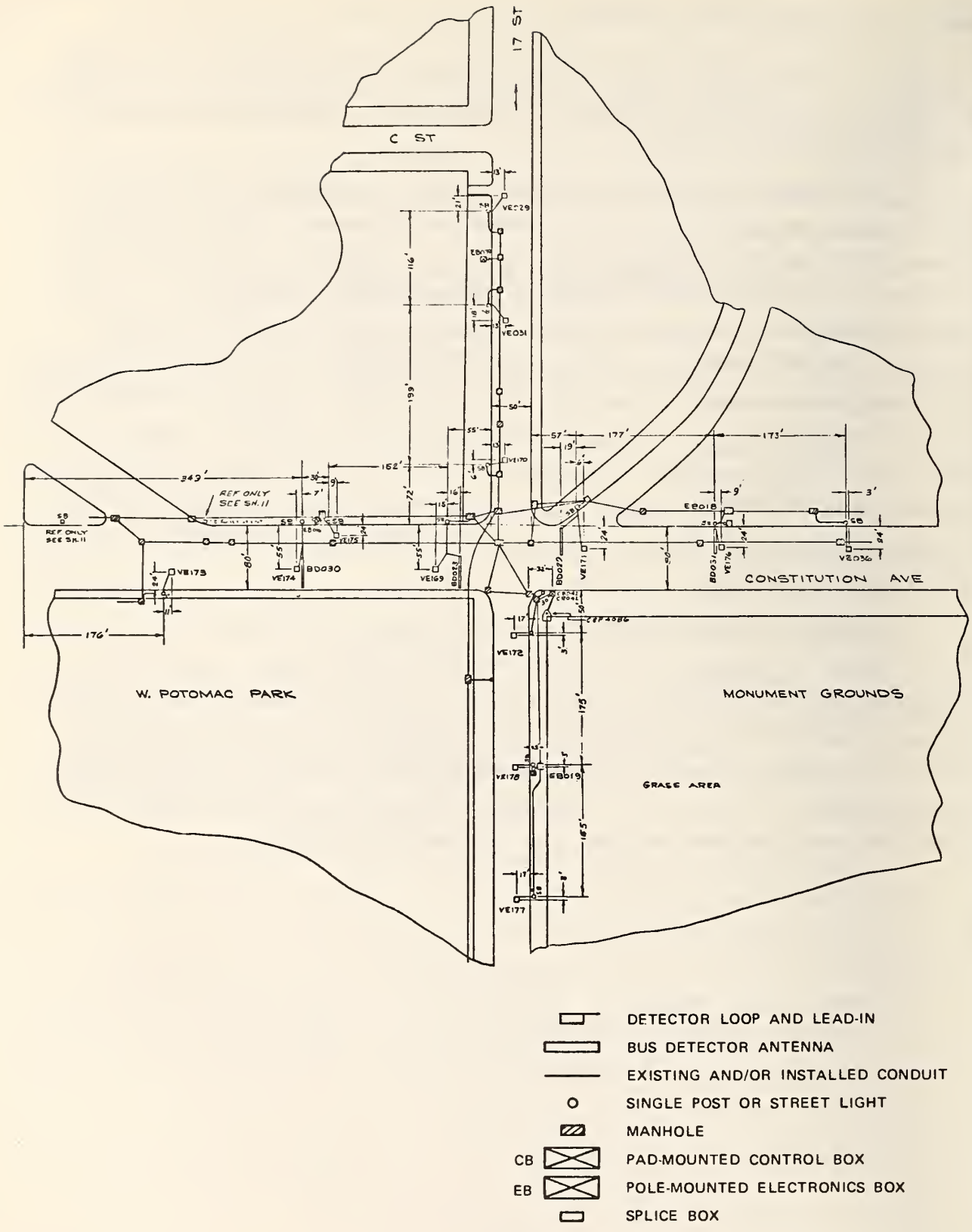

Figure 3-12 Detail of UTCS Street Installation Drawings

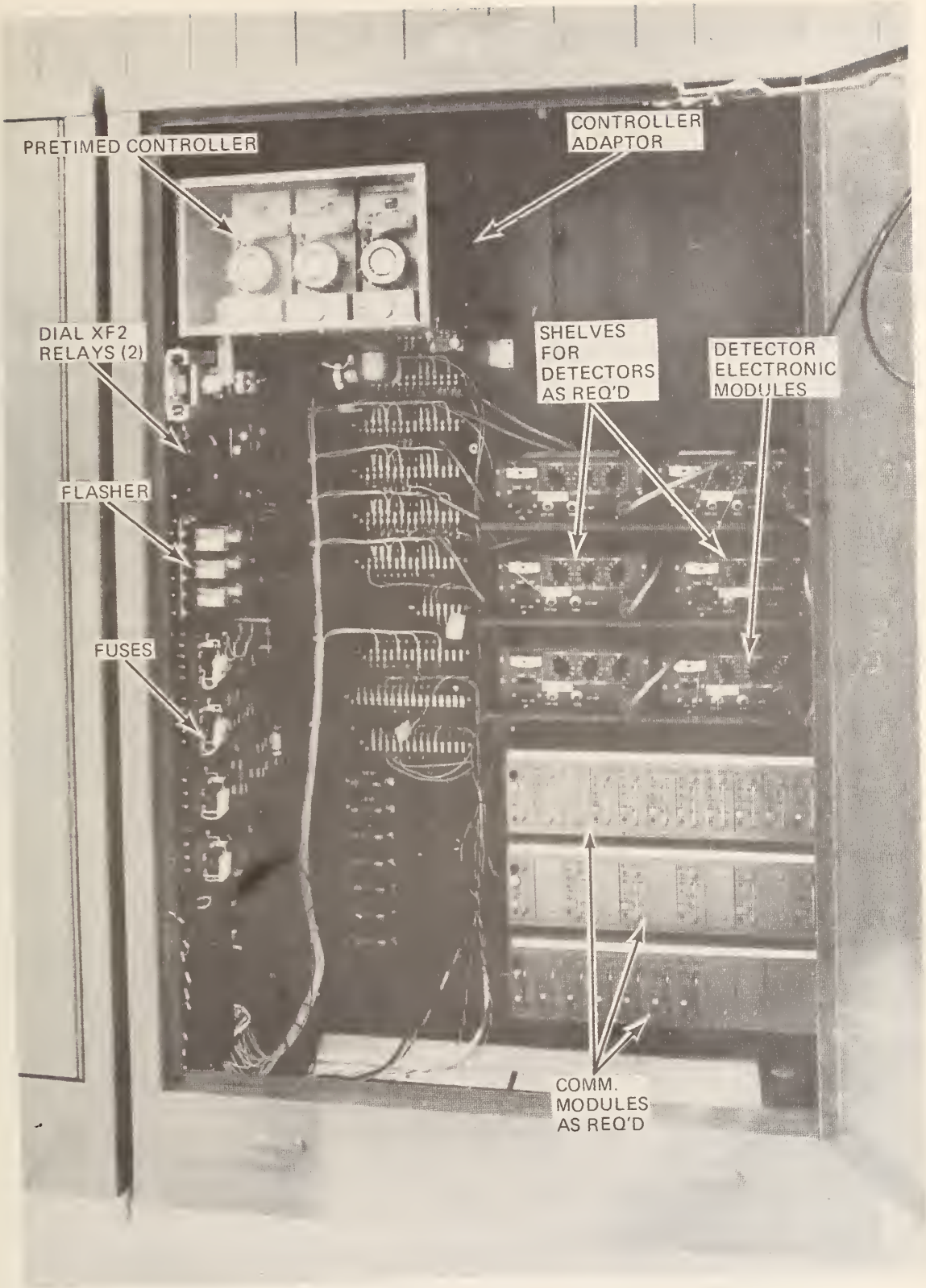

Figure 3-13. UTCS Pre-Timed Controller Cabinet Installation

SECTION 4
CENTRAL SYSTEM DESIGN

This section describes the basic approach taken in designing a traffic control system central complex. Each of the major tasks which must be completed in designing the central system is discussed in detail, including computer system design, displays and controls design, and room layout and design. Some alternate configurations are presented and related tradeoff factors are discussed. Examples of similar designs are also given to elucidate the differences in the various design approaches. The factors affecting the UTCS design and the final UTCS design configuration in each category are also presented.

4.1 COMPUTER SYSTEM DESIGN

4.1.1 GENERAL CONSIDERATIONS

A. Input Parameters

An estimate of the required computer processing capability for a traffic control system requires an analysis of the functions which must be performed by the computer. Typical functions are expressed in parameters such as:

- Total number of intersections
- Total number of input and output discretes
- Timing requirements
- Number of traffic patterns
- Traffic control algorithms and special functions
- Print-out and display formats and frequencies
- Non-intersection discretes (ramps, signs, etc.).

The totality of functions required form a set of input, output, and processing functions, generally involving a time parameter or constraint such as discretes per second or response time. In order to gauge the effect of the functional requirements on the computer design task, it is necessary to translate these requirements into computer-oriented parameters related to processing capability.

The processing capability of a digital computer system is expressed in parameters such as:

- Processing speed
- Word length
- Instruction set efficiency
- Input/output capability
- Storage capacity and access characteristics
- Manufacturer-supplied software capability.

Processing speed is, in general terms, the number of separate operations the computer can perform in a given time period (operations per second). It may be expressed as the number of short execution-time instructions (such as addition) which can be done in a second. However, in most cases, a more realistic measure is based on an appropriate mix of instructions having both short and long execution times.

Word length is an important measure of processing capability in that it is directly related to efficiency of memory addressing and data handling as well as arithmetic precision; the latter being of minor importance in this application. The higher cost of long words must be considered in making a selection.

Instruction set efficiency is a significant indicator of processing capability, but is difficult to measure because the type of program being used has a bearing on the suitability of particular instructions. For traffic system application, where large numbers of arrays are manipulated, indexing, indirect addressing, fractional word handling, and stack processing instructions are important. The number of hardware registers, priority interrupt controls, and floating point hardware features also contribute to overall instruction set efficiency.

Input/output capabilities are best measured by the rate at which data can be transferred from peripheral and external equipments to the computer, by the capability for concurrent processor and I/O operations, by the priority structure of the I/O control system, and by the ability to transfer data directly into and out of memory. In the case of traffic control, most of the input and output data from intersections is in the form of discretes which can be packed into data words for parallel transfer into the computer.

Storage capacity is the amount of core memory plus mass storage available to the central processor. The mass storage media may be disc, drum or magnetic tape. The mix of mass storage devices and their I/O rates for a particular system are determined by the nature of the application. For applications in traffic control, where large amounts of data are being handled and fast response is required, a relatively large core memory and a fixed-head disc memory are usually needed.

Software provided by the computer manufacturer has an important impact on processing capability, as well as contributing to programming manpower efficiency. Such software includes assemblers, compilers, I/O routines, operating systems, diagnostic routines, and library packages. Efficient, comprehensive, and completely debugged software is required for this application.

Using requirements imposed on the computer by the functional requirements of the problem, a first estimate of the computer processing capability can be generated. This operation is a broad statement of the computer system requirements, and is only the first step in an iterative process which eventually results in detailed computer specifications. In addition to the requirements imposed by the functional aspects of the problem, the final computer requirements will be influenced by the configuration which is chosen, by cost tradeoffs, and by the requirements of other system elements. For example, most real-time applications require some compromise in storage allocation between core and peripheral storage. The time delays associated with peripheral storage devices are generally intolerable for programs such as the software operating system, and for many real-time application programs. There is, however, an optimum balance to be achieved between core and peripherals. This compromise is reflected in the computer system configuration ultimately chosen, and directly affects final hardware and software specifications. A typical specification for a central site computer system installation is included in Appendix D and a computer system evaluation work sheet in Appendix G.

Required processing capability can also be influenced by cost factors associated with other system elements. For example, if savings can be effected by reducing the number of required telephone lines, some processing may be done at remote locations. Remote minicomputers or data concentrators would allow data for many sources to be multiplexed over a single telephone line between the remote and central processors.

The set of computer requirements resulting from the initial sizing operation can synthesized into a large number of different system configurations. Some of the possibilities are better suited to a specific application than others.

The procedure for selection of the optimum computer system configuration involves:

- Synthesis of a set of candidate configurations
- Tradeoff analysis on the advantages and disadvantages of each candidate.

The set of candidates selected for evaluation must be both comprehensive and concise, and should not include many candidates which are only minor variations of each other.

Tradeoff analysis of the candidate configurations is based principally on the following system parameters:

- Functional requirements
- Hardware capabilities
- Software requirements
- Cost factors.

The analysis must also give consideration to other factors such as:

- Schedule requirements
- Reliability and maintainability
- Operational constraints
- Back-up requirements
- Operating personnel requirements
- Man-machine interface considerations.

Any of the latter factors can, of course, substantially affect the final selection of the computer system. However, the impact is more difficult to estimate early in the selection process than that of the first four system parameters.

The formal tradeoff process is begun with a listing of the candidate system parameters, and the assignment of weighting factors to each parameter in order to determine the optimum candidate configuration.

B. Alternate Computer Configurations

Computer system configurations which can be considered are discussed below. Discussions cover the basic organizational concepts and their potential advantages and disadvantages. It is not intended that these configurations be a complete set of candidates, but are intended simply to illustrate the range of possibilities involved.

The computer system configurations to be discussed are:

- Single central computer (Figure 4-1)
- Central computer with multiple processors (Figure 4-2)
- Central computer with minicomputer input/output (Figure 4-3)
- Central computer with one or more remote minicomputers (Figure 4-4)
- Multiple computer centers (Figure 4-4).

(1) Single Central Computer

The single central computer is a basic system configuration. The computer handles all traffic signals and detector outputs in an on-line, real-time manner. The major elements which make up this computer configuration (Figure 4-1) are:

- Processing unit
- Core memory
- Peripheral memory
- Input/output control
- Multiplexer.

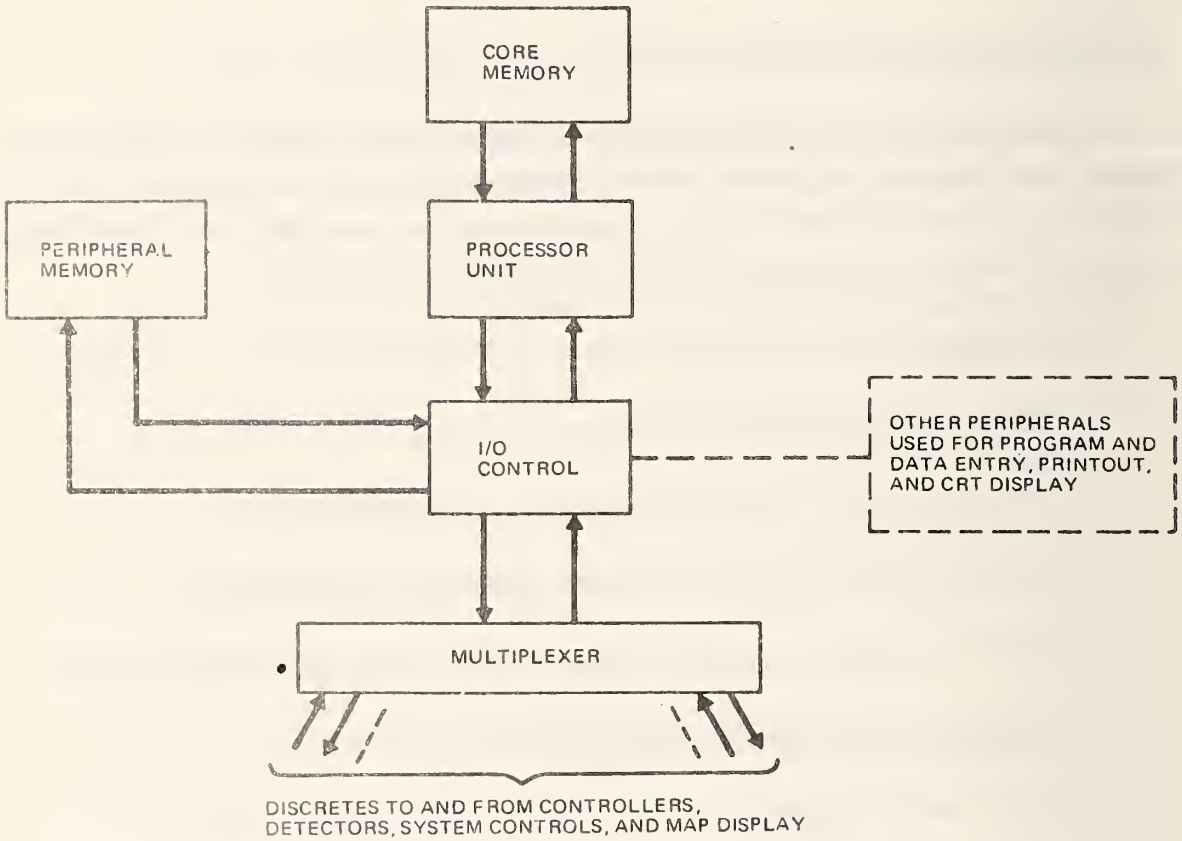
CORE MEMORY
PERIPHERAL MEMORY
PROCESSOR UNIT
I/O CONTROL
OTHER PERIPHERALS USED FOR PROGRAM AND DATA ENTRY, PRINTOUT, AND CRT DISPLAY
MULTIPLEXER
DISCRETES TO AND FROM CONTROLLERS, DETECTORS, SYSTEM CONTROLS, AND MAP DISPLAY

Figure 4-1. Single Central Computer

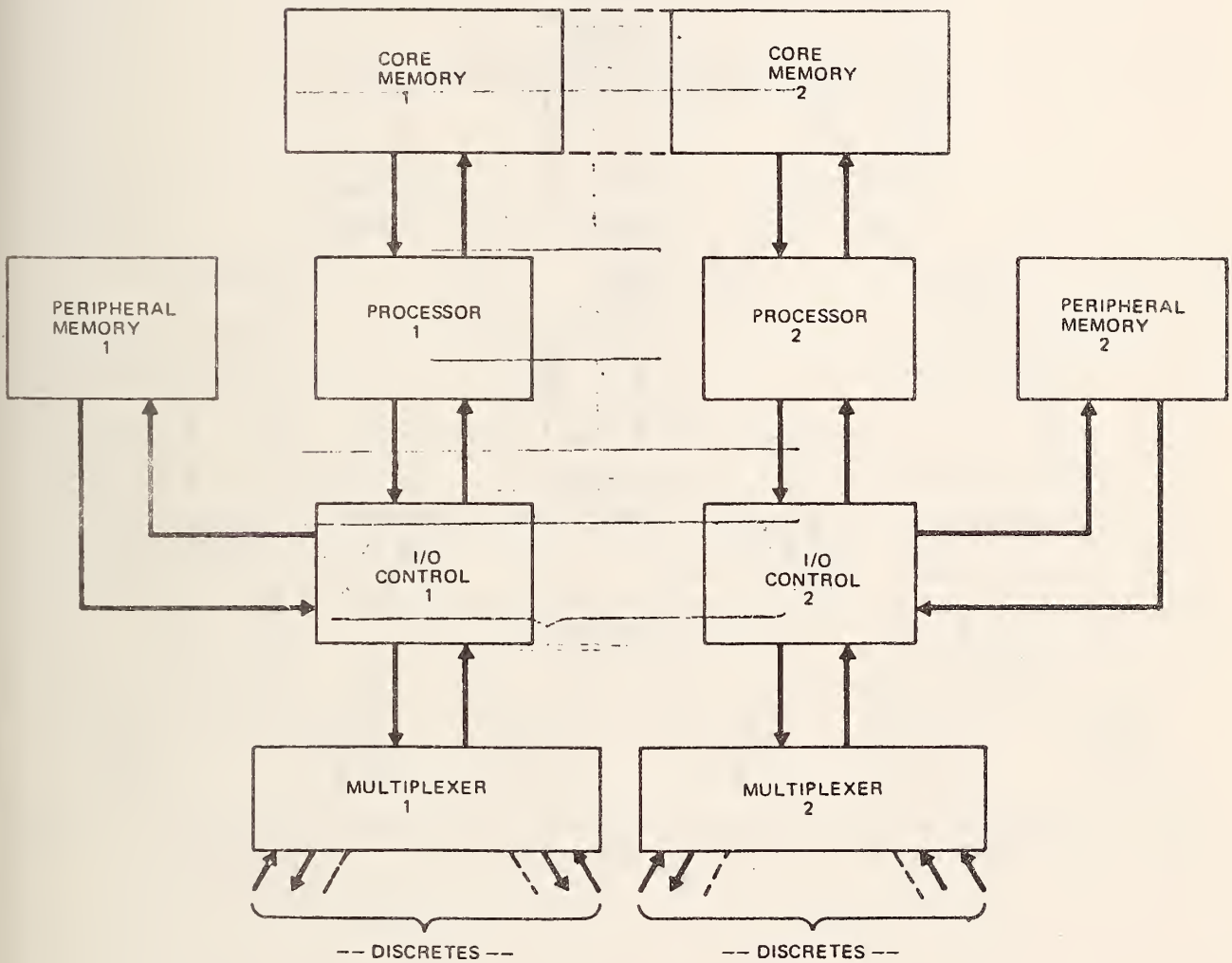

Figure 4-2. Central Computer with Multiple Processors

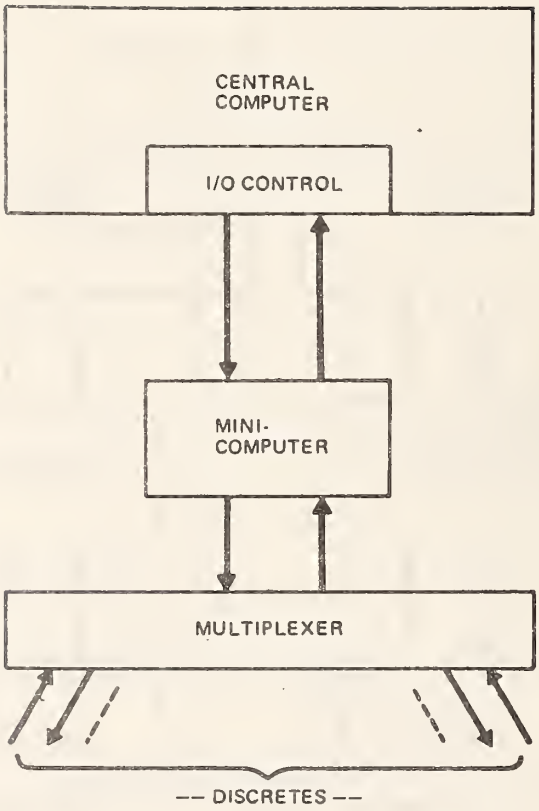

Figure 4-3. Central Computer with Minicomputer Input/Output

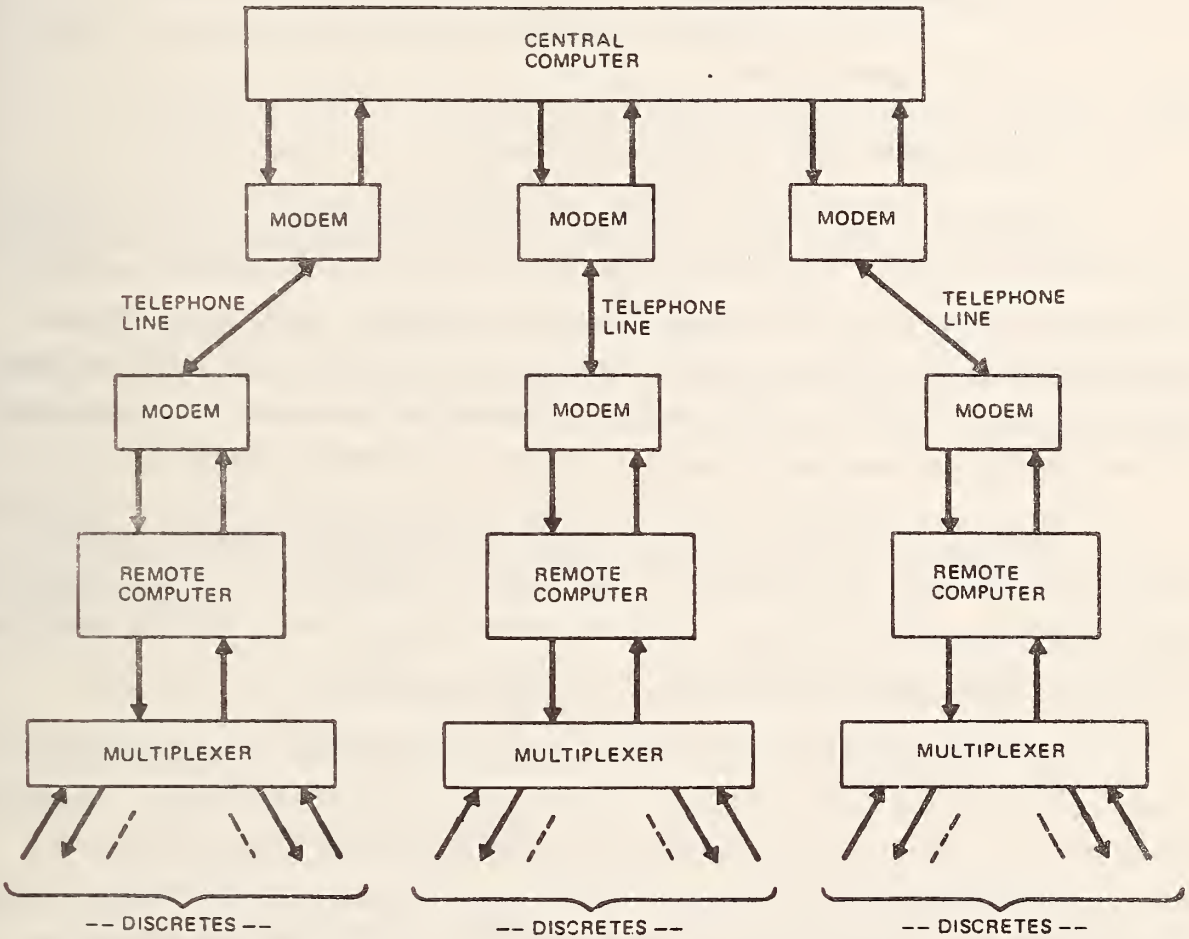

Figure 4-4. Central Computer with Remote Computers

The single processor handles all processing functions for the entire system. These include:

- Control of individual traffic signals
- Sampling all detector inputs
- MOE calculations
- Pattern algorithm selection and control
- Program and data inputs
- Control panel inputs
- Map display, CRT display, and printouts.

In batch process computer applications (EDP installations), it is a generally accepted rule that a single computer organization provides the most efficient use of the processing power inherent in a given set of computer equipment. The single software operating system can handle many application programs, and as the number of functions handled increases, the incremental computer equipment cost decreases. A single computer configuration is also often the optimum choice for real-time systems.

However, the single central processor approach has a number of potential disadvantages, including inefficient use of sophisticated capability for simple I/O processing, lack of back-up capability, increased communications costs, and high initial cost. These disadvantages are discussed in the following paragraphs.

a. I/O Processing. In a real-time control application, the computer must process input and output control functions within system-imposed constraints. Generally a large number of relatively simple operations must be performed in a short time. In a traffic system application, these operations involve the handling of sensor outputs, supplying advance pulses to the individual intersections and monitoring the controller operation.

The effect of the real-time input/output requirement is to use up relatively large amounts of the computer's processing power, and to increase the requirement for core memory. For a specific application, this effect may force the use of a more costly

computer than would be necessary if the real-time processing were not required. Most likely, this would be a computer with faster memory cycle time and a more sophisticated processor. In many cases, an alternative to this step upward is the use of a minicomputer to handle the fast but relatively simple real-time processing, as discussed below. The processed data are then transferred to the main computer at a relatively slow rate.

b. Back-Up. While the central processor is likely to be one of the most reliable units in the entire system, the single computer configuration provides no back-up in the event of processor failure, other than return to local intersection control. Some real-time system installations use dual processor unit and dual peripheral storage devices to help avoid this problem and thus enhance system reliability.

c. Communications. Although voice-grade multiplexing devices permit transmission of multiple signals over a single telephone line, a complete system involving a large number of intersections (1000-2000) may require a large number of telephone lines converging on the central site from diverse areas throughout the controlled complex.

d. Initial Cost. Choosing a central computer with the potential capacity for handling as many as 1000-2000 intersections could involve an initial capital outlay which is greater than would be required, if more than one processor were used for the total system, even though some incremental add-on capability can be achieved with core memory modules and peripheral storage units. Choice of a single processor, which is powerful enough for the total job, may also involve longer lead time in the procurement of the computer equipment.

Each of the candidate configurations discussed in the following paragraphs overcomes one or more of the potential disadvantages of the single computer approach.

(2) Central Computer With Multiple Processors

The multiple processor configuration operates in essentially the same manner as the single processor configuration, except that the total processing task is shared

between two or more processors. This has the obvious advantage of avoiding dependence on a single processor, and the basic configuration can also be used to provide various levels of back-up in the event of computer equipment failures.

Figure 4-2 illustrates a multiprocessor configuration using two processors in which each of the processors has its own dedicated peripheral memory, and either a shared or dedicated main memory. In this configuration, the real-time input/output processing is shared by two processors. Assuming even distribution of processing load, each of the processors must provide only one-half the processing power for input/output operations.

The simplest implementation of this configuration is to divide the total system task among the processors and allow each to operate independently. This approach lends itself to stepwise expansion from about 150 intersections to 2000 intersections.

A minor variation of the completely dedicated processors is to share common core memory between the two processors as indicated by the dashed lines in Figure 4-2. This approach reduces the core memory required but each processor still retains autonomous operation. Another variation, which reduces autonomy but may also reduce costs, is to share peripherals through a common I/O control.

Some back-up capability can be provided by physically switching units of computer equipment among the processor configurations when a unit fails, and when it is determined that the portion of the system which has gone off line has a higher priority than some other portion which is still operating. If removable disc packs are used, for example, these can be easily switched among disc drives. If it is decided that the entire system should operate in a degraded mode when a piece of computer equipment fails, a program for degraded back-up can be read into the system from magnetic tape.

(3) Central Computer With Minicomputer Input/Output

This configuration (Figure 4-3) makes use of a minicomputer to relieve the central processor of the task of processing the real-time discretes received from the detectors and controllers, and discretes sent to the controllers. Figure 4-3 shows a single processor central computer; however, the same concept is equally applicable for a multiple central processor configuration.

As was mentioned previously, the task of handling real-time inputs and outputs can use up large amounts of available processor capability. The processing of detector and

intersection control discretes involves simple operations for each discrete, but these operations are done repeatedly, due to the large number of discretes involved. This type of processing is well-suited for the typical minicomputer which has a limited instruction repertoire and word length. However, its capability in number of operations per second can rival that of very large computer installations. Thus, a relatively modest investment in equipment could result in significant savings if it reduces the required central computer to a less powerful version. Alternatively, use of the minicomputer can provide an added margin of processing power to the overall system design.

The configuration of Figure 4-3 shows all real-time discretes being handled by the minicomputer. For some applications, it may prove more advantageous to have the minicomputer handle only the highest rate discrete inputs, which, in the case of the traffic system, would be the sensor discretes. Discretes for control of the interseetion controllers would then be handled directly from the central computer.

(4) Central Computer with Remote Minicomputer(s)

In this configuration, minicomputers are used to perform the same real-time input/output processing function described in the preceding examples. However, in this configuration more than one minicomputer is used, and they are located in different locations remote from the central computer. Figure 4-4 illustrates this configuration.

Where a minicomputer is used to handle the processing of real-time discretes, the requirements for data transfer between the minicomputer and central computer can be made relatively low. The configuration shown in Figure 4-4 takes advantage of this fact in order to achieve a reduction in the total number of telephone lines required by the system. Data are transferred from intersections and detectors to the minicomputer over telephone lines using voice-band multiplexing techniques such as FDM or TDM as in the standard central computer approach. Data processed by the minicomputer, and signal interval update information from the central computer, are transferred by a time-division multiplex technique over a standard telephone line. A 1200-baud transfer rate should be capable of handling two-way data transfers for this application. By strategically locating minicomputers throughout the control area, savings may be achieved in the length of telephone cabling required by the traffic control system.

The use of remote minicomputers presents additional problems in system maintainability, since all computer equipment is not located in one central location. Also, to be a viable approach, the minicomputer should be capable of operating unattended like other

system field equipments. This presents a special problem for the program stored in the minicomputer memory. The data stored in a core memory are not volatile and should remain in the memory for an indefinite period. However, power transients can, on occasion, cause memory to be lost, and the entire program must then be reloaded into the core memory.

One solution to this problem is to have the program wired into a read-only memory (ROM). Since the program will be relatively small for this application, this approach does not add appreciable cost to the system. One disadvantage is that the program is fixed, and any changes require rewiring of a new ROM. Again, the size of the program and the fact that only simple operations are performed probably mean this is not a great disadvantage for this application.

Other approaches to program loading also deserve consideration. Since the minicomputers are connected to the central computer by a data line and the program is small, the central computer could load the program over this line in the event that it is lost from the minicomputer memory. Another approach is to have the program on a mylar tape loop at each remote site. Upon command from the central computer, the program would be loaded into the minicomputer core memory.

(5) Multiple Computer Centers

This configuration uses two or more computer installations located in separate areas of the control complex. If there are just two separate computer facilities, the functional operation is not very different from the two processor candidates described previously.

The potential advantage of separate computer facilities lies in the savings realized in the length of telephone lines where control areas are widely separated. There may also be some advantage in having separate control consoles and displays manned by traffic engineers, each exclusively devoted to the particular areas served by that computer facility.

However, information on the status of each area, if the goal of a coordinated traffic system is to be realized, would still have to be transmitted to the central site. The amount of data to be transmitted for this purpose, and the program complexity introduced, would have to be estimated in order to establish the feasibility of this configuration.

Choice of this configuration requires duplication of computer equipment, physical facilities, and manpower. If only two sites are involved, the duplication of equipment and

This is probably not too significant in comparison to the other multi-computer configurations discussed earlier, and in light of the communications lines which would be eliminated. If more than two sites are used, the duplication of equipment and facilities could become a significant factor.

In all cases, however, the duplication of manpower resources involved is a significant expense. Using more than one computer site will involve additional highly-skilled computer operators, programmers and, possibly, maintenance personnel. Additional traffic engineers may also be required to man the multiple sites. Personnel costs and the difficulties in obtaining the required level of personnel could easily outweigh the savings realized in communication lines.

4.1.2 UTCS COMPUTER SYSTEM

A block diagram of the UTCS/BPS integrated computer system and data processing equipment is presented in Figure 4-5. Figure 4-6 shows a breakdown of the UTCS/BPS computer/peripheral control configuration. The interconnection and data flow for specific traffic-oriented equipments such as the control panel, map display, CRT displays, communications, and radio link are indicated. Standard computer peripheral equipments such as discs, CIU, magnetic tapes, card reader, and TTY's are also indicated.

A. UTCS/BPS Computers

UTCS and BPS operations are combined, utilizing two CPU's in a dual processor configuration. The integrated computer system is composed of two XDS Sigma 5 computers and a core memory (used by both computers) of 65,536 32-bit words. Together, the two units occupy seven cabinets; the floor plan is shown in Figure 4-7. This system provides growth potential through the availability of two central processor units as well as because of its 32-bit word length and permits upward growth through software applicability to more powerful machines.

The efficiency of the dual CPU approach derives from the common data base of the UTCS and BPS parts of the system. Since both CPU's have access to the same core locations, data base duplication (requiring costly core memory) is eliminated. Additionally, transmission of data from one machine to another, which would be time-consuming and would increase programming, is eliminated.

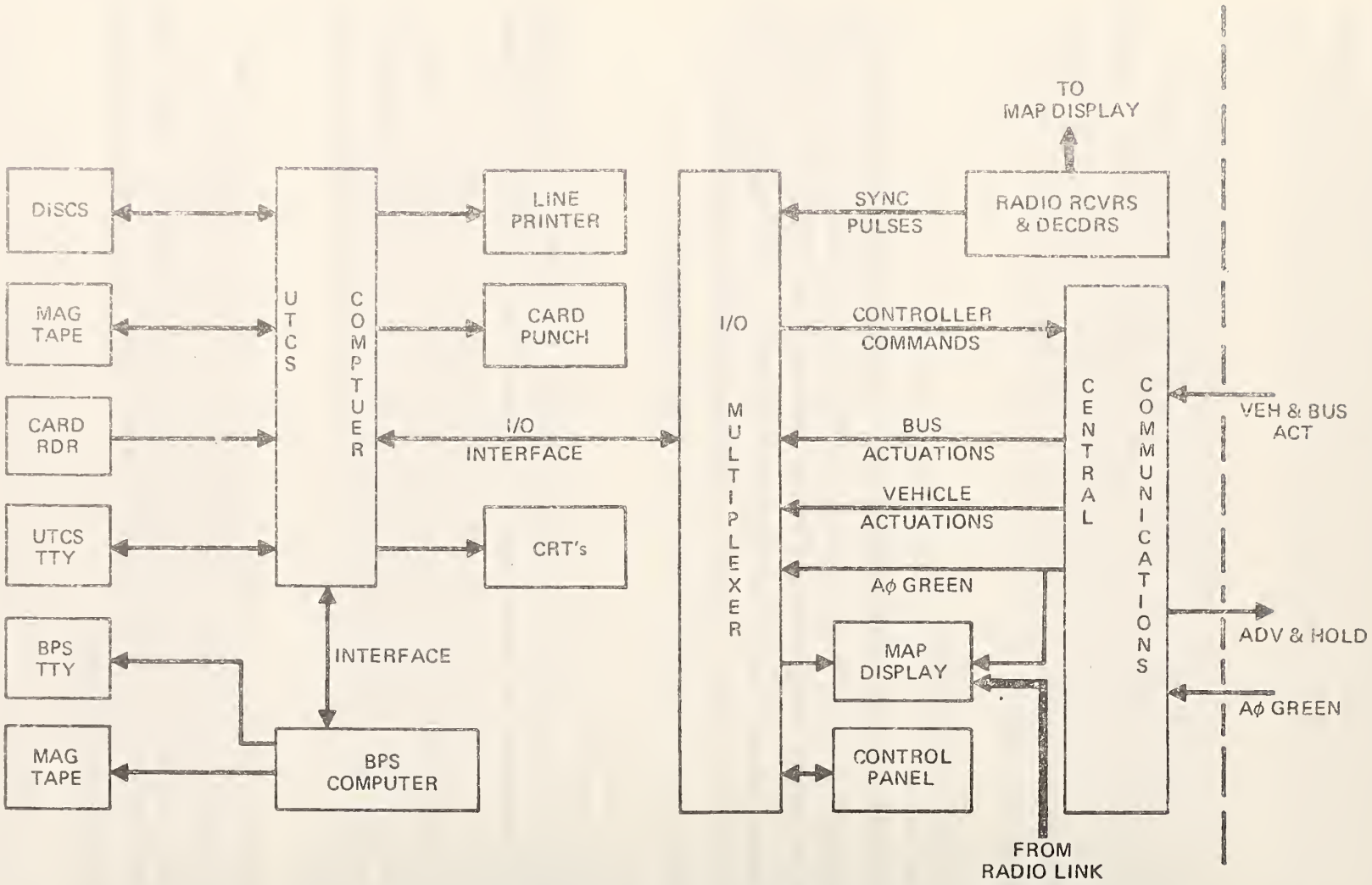

Figure 4-5. UTCS/BPS Data Processing Equipment

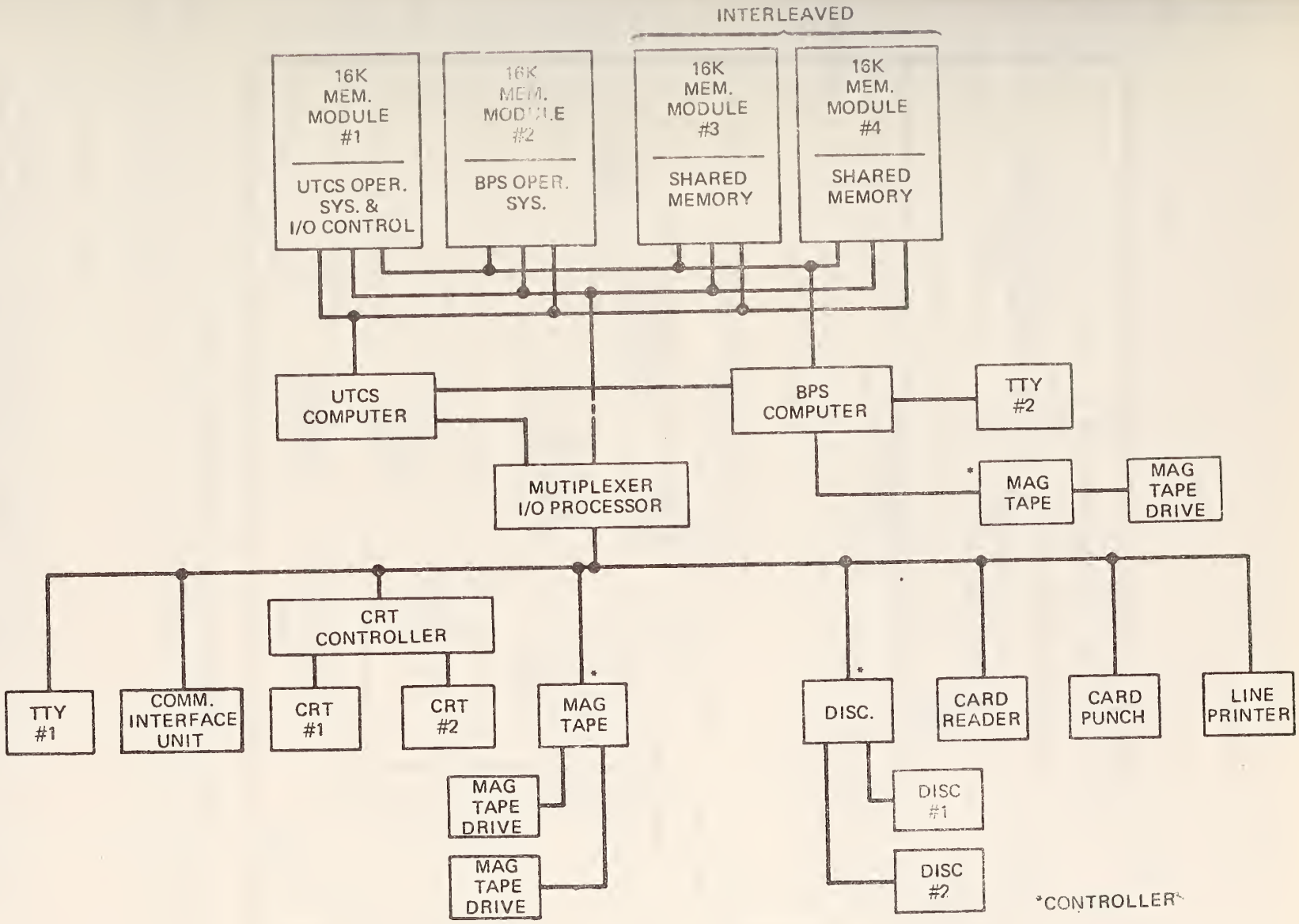

Figure 4-6. UTCS/BPS Computer Control Configuration

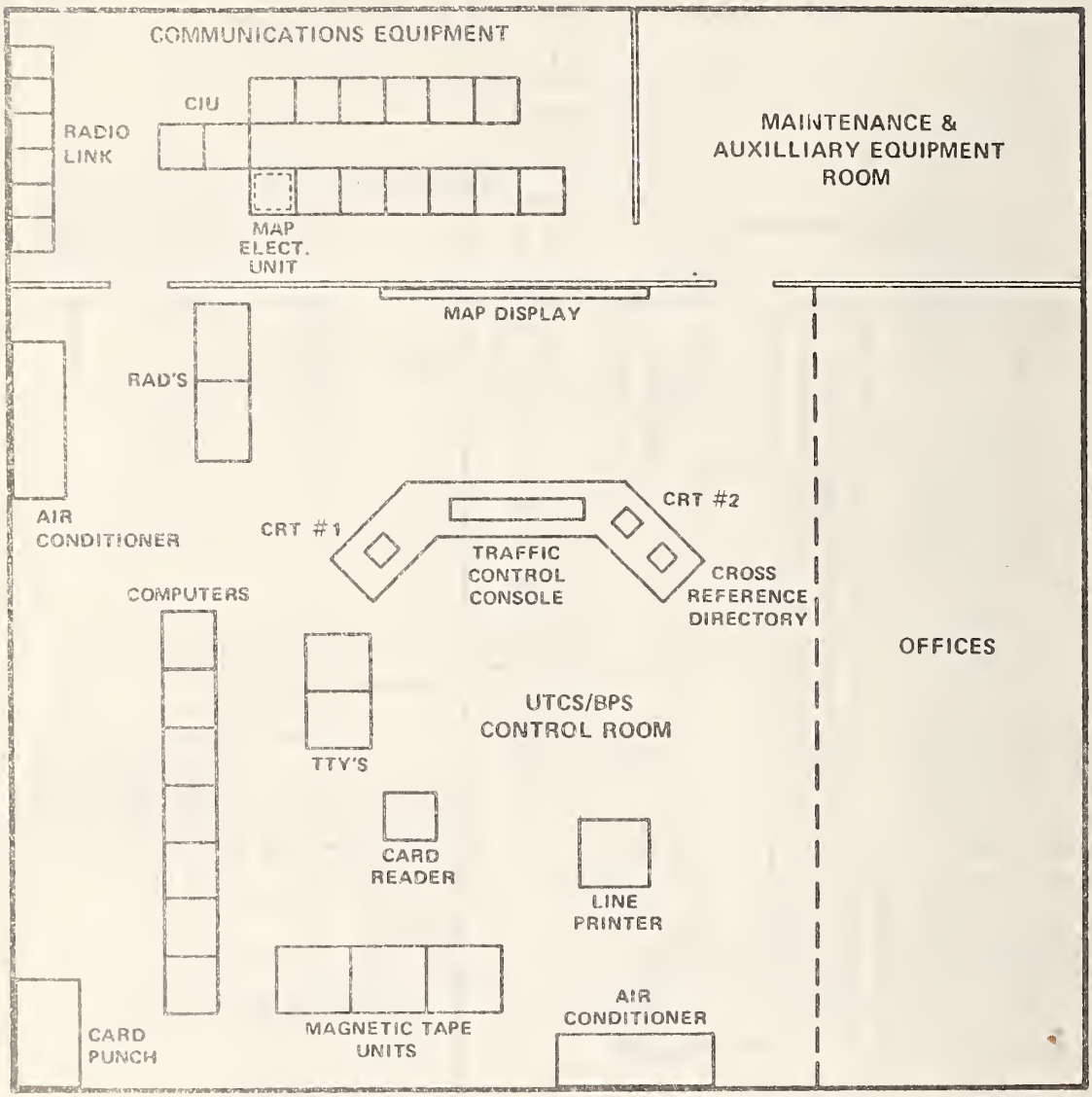

Figure 4-7. Floor Plan of UTCS/BPS Washington, D. C., Control Center

In addition to core storage, peripheral storage is provided by Rapid Access Data System (RAD) and 7-track magnetic tape drives. Two RAD's, supplying 1.5 and 3 megabytes of storage, are used to store the operating system program, the UTCS and BPS programs, traffic patterns, and start-up parameters. Two tape drives are controlled by the UTCS CPU and may be used to boot the operating system on to the RAD's or to store computed UTCS and BPS measures of effectiveness (MOE's). A third tape drive is controlled by the BPS CPU and is used to store raw vehicle and bus detector data. A line printer controlled by the UTCS CPU is used to provide hard copy records of the 15-minute and end-of-day reports. Two Hazeltine 2000 CRT units are used to provide UTCS and BPS system data that are requested by the operator. The requests are made from the control panel. The control panel is also used to select the modes of operation of the system and the type of map display desired. Additional peripheral units controlled by the UTCS CPU are 80 column card punch and card reader units. Each of the CPU's also has its own teletype unit.

B. UTCS/BPS Program Organization

The computer routines are organized in accordance with the frequency at which the various functions are required to be performed. Functions that are performed at least 32 times a second are specified in routines that are designated Priority Level 1. Priority Level 2 routines are those that are entered twice a second. All the remaining routines that involve cyclic operations are assigned to Priority Level 3. The timing for Priority Level 1 routines is controlled by a clock which causes a program interrupt at the required frequency. When the interrupt occurs, the routines are executed and several software clocks are updated. When the 1/2 second mark is encountered, the Priority Level 2 routines are entered. When they have been completed, the Priority Level 3 routines are resumed at the point at which they had been interrupted.

(1) Priority Level 1

Priority Level 1 routines embody those functions which are directly associated with the measurement of vehicular traffic. The sequence of functions performed in this level is illustrated by Figure 4-8.

(2) Priority Level 2

The Priority Level 2 routines are primarily those associated with controller commands, error checking, and data evaluation. The routines that comprise Priority

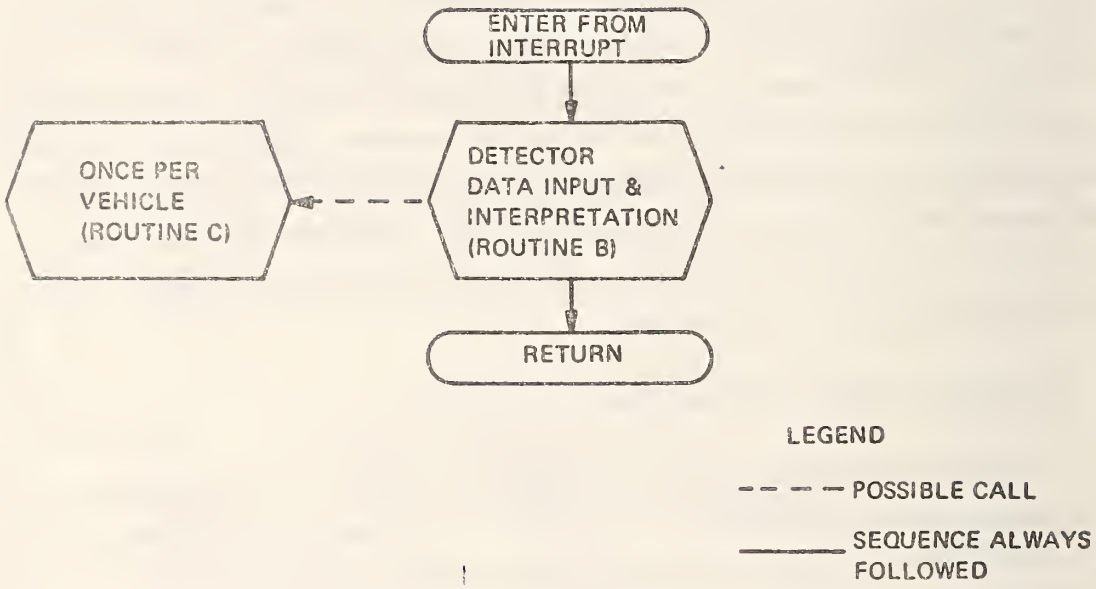

Figure 4-8. UTCS Priority Level 1 Routines

Level 2 and their relationships are illustrated by Figure 4-9. Centered around the Priority Level 2 functions are a sequence of routines performed for each controller. These routines, which are included in the "Do-Loop" in Figure 4-9, provide the functions of sequencing the controller through its cycle, placing it on or off line as desired, and adjusting split and offset in accordance with traffic volumes or operator commands. Other Level 2 routines provide error checking for each controller as well as for the computer itself, controller cycle time keeping, data computation, and the operation of semi-actuated controllers.

(3) Priority Level 3

The Priority Level 3 routines provide the display and operator interface functions. Those data evaluation functions for which time is not critical are also performed by Priority Level 3 routines. The routines that comprise Level 3 are shown in Figure 4-10 in the sequence which they are entered. Each routine is called by the Level 3 Executive routine and returns to the Level 3 Executive when it is completed.

C. UTCS/BPS Timing and Storage Requirements

The UTCS/BPS program and data base include both UTCS and BPS routines. BPS routines are exclusive. However, some UTCS routines (H, I, K, M, Q and Y) include BPS functions. The storage and timing contribution of the BPS functions in the UTCS routines are not conveniently separated out and, therefore, are included in the UTCS totals.

The storage totals for the UTCS/BPS in its present configuration are:

BPS - 4854 words
UTCS - 35,468 words

A summary of the timing requirements is given in Table 4-1. Values are broken down according to UTCS or BPS routines and according to the priority level.

TABLE 4-1. UTCS/BPS COMPUTER TIMING SUMMARY

System Function	Priority Level	Time Loading (msec/sec)
UTCS	1	163
BPS	1	49
UTCS	2	140
BPS	2	48
UTCS	3	0.05

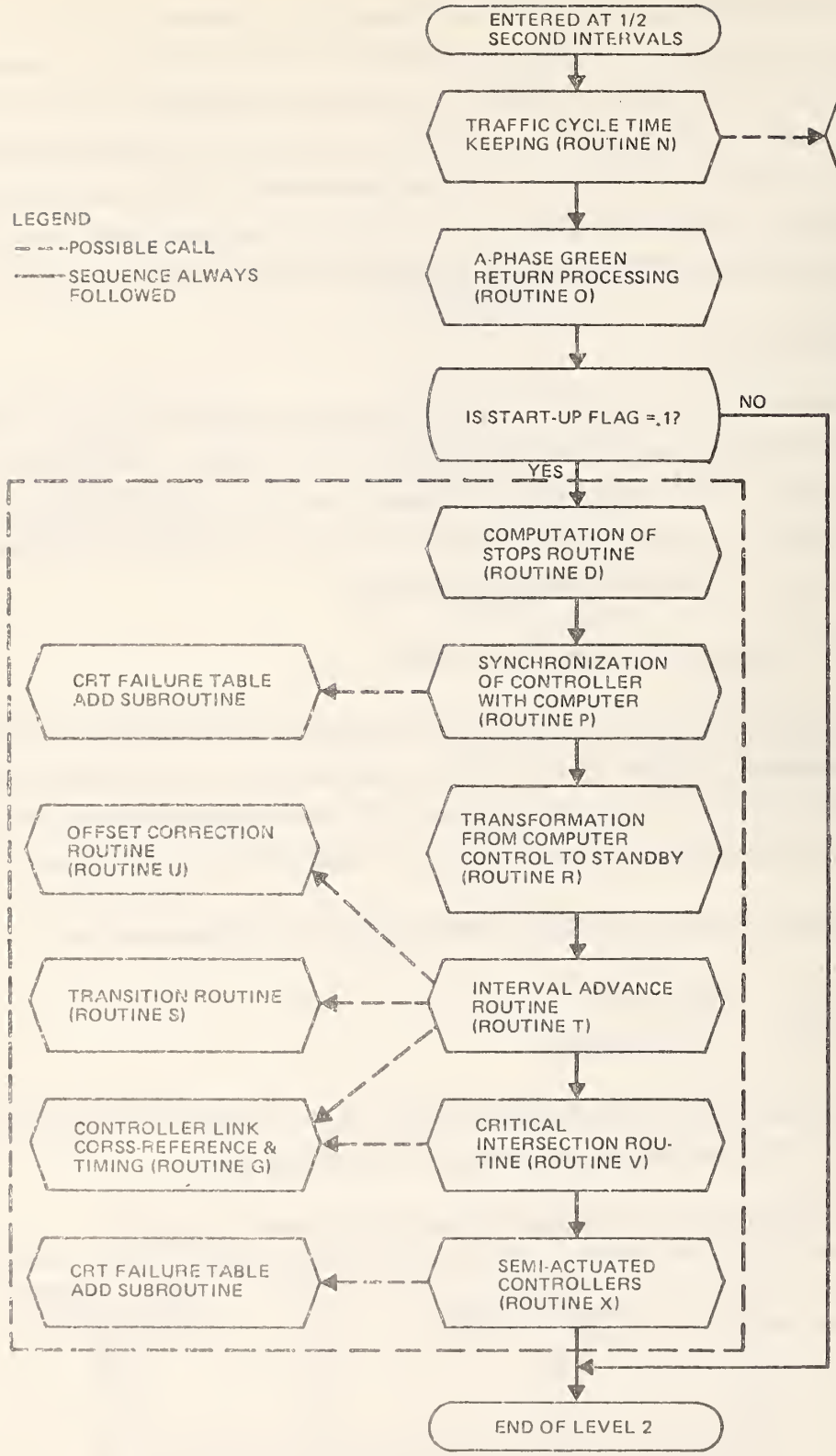
ENTERED AT 1/2 SECOND INTERVALS
TRAFFIC CYCLE TIME KEEPING (ROUTINE N)
CYCLE TIMING SUBROUTINE
LEGEND
POSSIBLE CALL
SEQUENCE ALWAYS FOLLOWED
A-PHASE GREEN RETURN PROCESSING (ROUTINE O)
IS START-UP FLAG = 1?
NO
YES
COMPUTATION OF STOPS ROUTINE (ROUTINE D)
CRT FAILURE TABLE ADD SUBROUTINE
SYNCHRONIZATION OF CONTROLLER WITH COMPUTER (ROUTINE P)
OFFSET CORRECTION ROUTINE (ROUTINE U)
TRANSFORMATION FROM COMPUTER CONTROL TO STANDBY (ROUTINE R)
TRANSITION ROUTINE (ROUTINE S)
INTERVAL ADVANCE ROUTINE (ROUTINE T)
CONTROLLER LINK CORSS-REFERENCE & TIMING (ROUTINE G)
CRITICAL INTERSECTION ROUTINE (ROUTINE V)
CRT FAILURE TABLE ADD SUBROUTINE
SEMI-ACTUATED CONTROLLERS (ROUTINE X)
END OF LEVEL 2

Figure 4-9 UTCS Priority Level 2 Routines

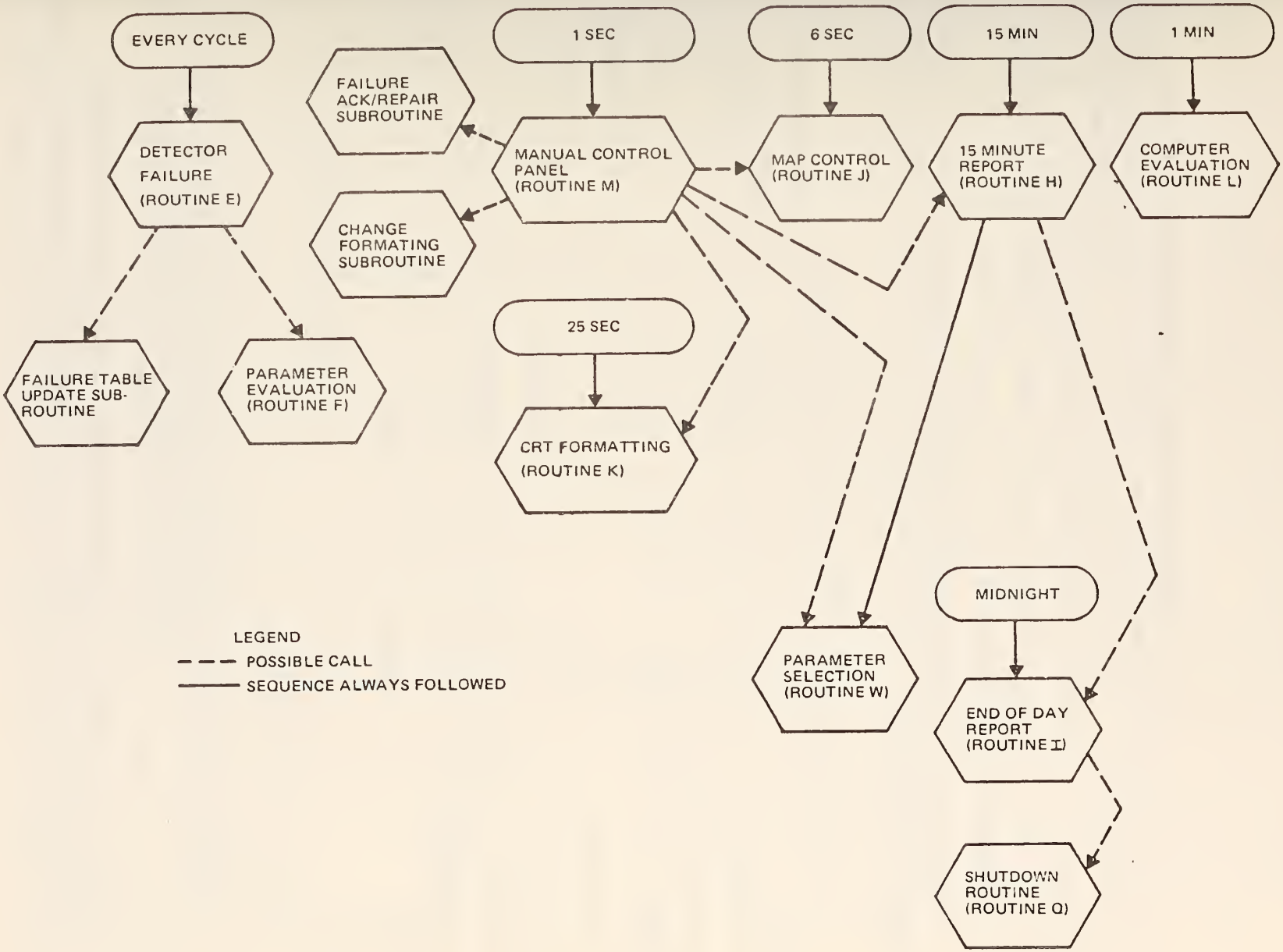

Figure 4-10. UTCS Priority Level 3 Routines

D. Computer/Peripherals Interface Characteristics

(1) Input/Output Data Rates

UTCS input/output data rates requirements are consistent with UTCS accuracy and performance objectives which were established as a result of the studies and analyses described in Reference 3B. Maximum quantities were based on a controlled complex of 220 intersections and 1000 detectors. The present UTCS data base provides for 111 controllers, 497 vehicle detectors, and 144 bus detectors, and is expandable with the computer system in its present configuration.

The quantities and data rates which are processed by the UTCS computer system are summarized in Table 4-2.

TABLE 4-2. UTCS INPUT/OUTPUT DATA SUMMARY

Signal	Type	Quantity	Repetition Interval (sec)
Vehicle Detector	Input	1000 (max.)	0.031
Controller Timing Status	Input	220 (max.)	0.5
Radio Link	Input	6	0.5
Traffic Control Panel	Input	111	1
Controller Advance	Output	220 (max.)	0.5
Controller Hold	Output	220 (max.)	0.5
Traffic Control Panel	Output	16	1
Map Display	Output	12	6
CRT Display	Output	2	25

(2) Computer Interface Unit

The CIU or I/O multiplexer provides the interface between the UTCS computer and external central peripheral equipments, and incoming and outgoing signals to central communications. The signal termination in the CIU include incoming vehicle and bus detector actuations, incoming controller A-phase green return signals, computer-generated outgoing controller hold and advance commands, command signals to the map display, synchronization signals from the radio link, and signals to and from the control panel. The

terminations are in a parallel configuration, that is, a line exists for each detector, controller, controller cycle synch pulse, etc. Signals at the terminal points are discrete signals which are nominally +6.5 volts for the on state.

The UTCS computer accesses the CIU sequentially on 32 lines. All of the terminal signal states are read into the computer, or transmitted from the computer, on a 1/32 second cycle basis.

(3) Map Electronics Unit

The map electronics unit, housed in a single cabinet, provides the interface between the CIU and the map display. It is used to decode the display code being outputted by the UTCS computer (refreshed every 6 seconds) and available at terminal points in the CIU. Twelve discrete lines are used between the CIU and this unit. Nine of the lines form a BCD code which define 512 unique control points on the map; two lines are then used to define the on-off state of two map lamps at each control point, thus providing control of 1024 individual lamps, and one line transmits the synchronization discrete signals. The present UTCS instrumentation utilizes only about 400 control points, thus permitting an expandability of better than 100 percent. The map electronics unit processes the code each time a change in the state of the synchronization bit occurs. This is programmed to change at a rate of 24 times over a 1/32-second interval.

(4) CRT Display Units

Two CRT's operate in conjunction with the Traffic Control Panel and the computer. The CIU transmits display page data serially over two lines at a 2400 baud rate. This corresponds to 240 characters per second, since the CRT uses a 10-bit character code. The computer refreshes the data transmission at a 25-second rate.

(5) Central Communications

Central communications provides the interface between the incoming and outgoing telephone lines and the CIU. Receivers are provided on incoming lines and transmitters on the outgoing lines. A summary of the interface relationships of the various signals with central communications and the CIU is presented in Table 3-8.

Central communications is composed of 10 cabinets (see Figure 4-7). Each cabinet is identically wired, providing channels for the various incoming and outgoing signals as follows:

- 16 2-frequency, A-phase green incoming signals
- 56 2-frequency, vehicle detector incoming signals
- 16 3-frequency, hold and advance outgoing signals
- 19 3-frequency, bus detector incoming signals
- 3 dual-channel audio amplifiers, incoming line conditioning amplifiers.

The total capacity of UTCS/BPS communications in its present configuration is for 128* controllers, 560 vehicle detectors, 190 bus detectors, and 60 incoming lines. Since the present UTCS/BPS complement is 111 controllers, 497 vehicle detectors, 144 bus detectors, and 55 input lines, the possible expansion of communications in its present configuration is for an additional 17 controllers, 63 vehicle detectors, 46 bus detectors, and 5 incoming lines.

Integrating the BPS into UTCS reduced UTCS communications expansion capabilities. The net communications cabinet space required by a bus detector incoming channel is twice the amount used by vehicle detector or A-phase green returns. This is so because the 3-frequency receivers currently used for BPS require two standard modules per channel. Thus, without BPS, 2 x 190 or 380 module spaces could have been utilized for additional controller input and output signals and vehicle detector input signals. In addition, the incoming telephone lines, loaded with 144 bus detector signals, could have been used for vehicle detector and A-phase green returns.

(6) Radio Link

The radio link consists of a radio receiver and electronics which are used to synchronize the UTCS computer cycles with the District's master clock. The receiver output is fed to six decoders which feed six channels. The discrete pulses are transmitted to the CIU in synchronism with the start of six different master cycle lengths. In addition, two discrete outputs are obtained from the decoders and are fed directly to the map display for illuminating the 15th Street and 17th Street one-way arrows at the appropriate time of day.

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*Reduced by 20% from a total of 160 to provide for minor phase returns for the map display.

(7) Magnetic Tape Units

Three magnetic tape drives are used by the UTCS/BPS system. Two drives are dedicated to the UTCS CPU. Either drive can be used, but not simultaneously. The units are used to load the UTCS/BPS program tape (when not loading from the RAD), to make a "save tape" of the UTCS/BPS program, and to make a tape of the 15-minute UTCS/BPS MOE's. The third drive, assigned to Magnetic Tape Controller D, is dedicated to the BPS CPU. It is used exclusively for the recording of the UTCS/BPS raw histories.

(8) Rapid Access Data System

The RAD is composed of two cabinets located to the right of the BPS CPU cabinets (Figure 4-7). It is accessed only by the UTCS CPU. The UTCS/BPS program (KING) and the total of the UTCS patterns are stored in the RAD. Program KING is read into the core memory as well as the appropriate UTCS patterns when the UTCS computer is brought on line. The RAD is normally accessed on a 15-minute cycle to transfer the appropriate section patterns into the core memory. In addition, it is accessed on demand for pattern transfer, whenever a manual pattern or time-of-day mode change is made by the operator via the control panel.

(9) Teletypewriters

Two TTY's are used; one is dedicated to the UTCS CPU and the other to the BPS CPU. The UTCS TTY is used to communicate with the UTCS CPU in starting up the UTCS/BPS program either from the RAD or from a system tape. The computer also communicates error messages via the TTY (e.g. operator keying errors, peripheral unit operation switching errors, and peripheral unit failure errors).

The line printer and magnetic tapes are continuously monitored while the UTCS/BPS program is in operation. An error message will be typed out, if an error condition exists, when the unit is commanded by the program.

The BPS TTY is used in conjunction with the BPS CPU. It prints out only those error messages concerned only with the BPS-dedicated magnetic tape unit and the generation of the raw history tape. It is not used to communicate with the BPS CPU.

(10) Line Printer

The line printer unit is used in conjunction with the UTCS/BPS program and is controlled by the UTCS CPU. It provides a printout of the UTCS/BPS 15-minute and end-of-day reports. Typical reports are presented in Appendix C. This device is used in both on-line and off-line operations.

(11) Card Reader

The card reader is used in conjunction with the UTCS CPU. It is used off-line for implementing program changes as well as with an off-line program for implementing pattern changes or additions.

(12) Card Punch

The card punch is used in conjunction with the UTCS CPU. It is used for outputting punched cards in conjunction with off-line programs. It is also used directly for card deck duplication.

4.2 DISPLAYS AND CONTROLS

4.2.1 GENERAL

A. Operator Functions

The principal operator functions are as follows:

- Implement strategic control plans and experiments. This task includes such operations as loading programs and data into the system, selecting control strategies and experiments, and ensuring that the system is operating according to the specified plans.

- Monitor equipment status and expedite repairs. This task includes the supervision of system alarms, malfunction indications, and equipment status indications so that control plans are altered to adapt to the failure, and appropriate repair action is undertaken and completed. The data which are required to accomplish this function include the following:

  - Display of controller failure as evidenced by failure of A-phase green check. Display of controller status in a geographically related fashion with other controllers.

- Display of detector malfunction as evidenced by too long a call or too few calls. These symptoms are not uniquely indicative of a detector link failure but may be caused by traffic conditions. Detailed analysis capability of the intersection if thus required. Both alphanumeric and geographically related presentations are desired.

- Display of computer failure.

- Special signal to alert operator that a failure has occurred.

- Monitor traffic. This task includes observing whether flow and congestion appear to be at reasonable or expected values. Non-reasonable performance must be classified into the following probable causes:

  - Poor operation of a strategic plan

  - Equipment malfunction which was not reported by the system

  - Flow breakdown due to local blockage conditions.

  Corrective actions would be taken accordingly. In the third situation a temporary local expedient might be utilized. The displayed data required to accomplish this function include the following:

  - For each section, display whether the system is on remote or local control, which control plan is in effect, which pattern is in effect, whether all controllers are in time with the pattern, and whether all detectors in the section are properly operative.

  - Display the traffic parameters, volume, occupancy, queue length, stops, speed, and delay as geographically related quantities. Also display them as alphanumeric quantities for comparison and rate measurement purposes.

- Evaluate control plans and experiments. The principal method for evaluating the effectiveness of the various control plans and local experiments which are implemented is by off-line data processing. Nevertheless a requirement may exist for shorter-term data evaluation to eliminate the less effective plans and thereby avoid congestion during experimentation. It may also be desirable to "tune" the individual controller

patterns to improve performance. The data requirements for this short-term evaluation appear to be closely allied with the traffic monitoring task requirements.

- Perform off-line functions. These tasks involve computer programming, assembling, compiling, data and program loading, off line data processing, and experiment evaluation. The display requirements here are principally to be able to provide computer programs and computer data outputs in printed form.

B. General Requirements of Displays

In addition to the specific operator functions, certain general display requirements are pertinent. For the continuous monitoring and evaluation functions the following must be satisfied:

- The operator must be able to see the displays while seated at the control console
- Operation of the system must not cause distracting noise in the vicinity of the control console
- The individual displays and controls must be capable of being organized and integrated into a control console area arrangement which is operationally efficient as well as aesthetically attractive.

The organization of the displays and controls necessarily force some constraints on system organization and operation. System operation, mode structure, section operation, individual controller operation, and failure monitoring must be compatible with the characteristics of available displays.

C. Candidate Displays

Table 4-3 shows how the various display types may be used to satisfy the requirements described above. It can be seen that functions A3, A4, and E2 can be satisfied only by a keyboard/printer (typewriter) connected to the computer. This is not unexpected since this device is the chief means of maintaining two-way communication with the memory and the principal means of operator control of most computers.

TABLE 4-3. CANDIDATE DISPLAYS

Function \ Display/Control Type	Alphanumeric CRT(w/o Keyboard)	Illuminated Map Display	Controller/ Detector Status Board	Keyboard/Printer or CRT with Keyboard	Traffic Control Panel	Line Printer
A. Implement Strategic Control						
1. System Operation & Control				X	X	
2. Monitor Operation	X		X	X		X
3. Program Query & Control				X		
4. Computer Control & Debugging				X		
B. Malfunction Monitoring						
1. Controller Failure Display	X		X	X		X
2. Controller Ops Related to Geographical Location		X				
3. Detector Failure Display	X		X	X		X
4. System Adaptation				X	X	X
5. Permanent Records				X		X
C. Traffic Monitoring						
1. System Status	X		X	X		X
2. Permanent Records				X		X
3. Traffic Variables						
a. Geographically		X				
b. Alphanumerically	X		X	X		X
D. Evaluation						
1. System Status	X		X	X		X
2. Traffic Variables						
a. Geographically		X				
b. Alphanumerically	X		X	X		X
E. Off-line Functions						
1. Data Readout				X		X
2. Computer Control				X		

Requirements B0, C2 and E1 can be satisfied only by the line printer or the keyboard printer. However, the high frequency of on-line data reporting and the large data output requirement for off-line operations dictates a preference for the line printer since its data handling ability is far greater than that of a keyboard/printer.

The overall system control and operation function, A1, can be satisfied only by the keyboard/printer or a specially designed system control panel. Control of component and system functions at a panel especially designed for this purpose is preferable to a configuration in which control is provided by communicating with the computer through a typewriter, card reader, or other general-purpose input output device. Typewriter control, for example, requires the use of a set of key words or codes which the operator must learn. In using a typewriter for control, the chances for operator error are increased due to lapses in recalling the correct code words as well as by erroneous key actuation.

Having chosen the combination of keyboard/printer, line printer, and traffic control panel, the remaining functions can be satisfied by either an alphanumeric CRT or a controller/detector status board in conjunction with an illuminated map display or a graphic CRT.

The factors which influence the choice between the controller/detector status board and the alphanumeric CRT include cost, development effort, and the capability of the accepting modes changes in the presentation format. It appears from initial estimates that the alphanumeric CRT may be somewhat higher in hardware cost. However, the CRT approach appears to have the overwhelming advantage in flexibility as well as significant advantages in console integration.

The factors which influence the choice between the illuminated map display and the graphic CRT include cost, development effort, impact and utility of display, and ease of format changes. While each approach requires development effort, the CRT approach appears to require significantly more effort in the software area. Because of the map display's capability of presenting all sections simultaneously to a number of observers, it must be rated considerably higher. However, the map display may require a separate cross-reference directory since it may not have space enough to show all the necessary controller and detector identity information. On balance, the illuminated map display is the preferred candidate, although the graphic CRT can be considered as an option for experimental purposes.

D. Control Panel Design

A properly designed traffic system control panel will permit an operator to control the system with maximum ease and minimum possibility of error both during normal operation and when equipment failures occur. The final design specification for the control panel will evolve from a logical process that is initiated with a functional functional definition followed by a functional design and generation of a complete procurement package.

The first phase in the design process of the control panel is to establish the system functional requirements. This includes identifying each operation that would be executed by a system operator and the probable sequence of execution. In addition, a study of the system malfunction detection philosophy must be included in the analysis to ensure that a satisfactory complement of failure annunciators is included in the design. For example, the control panel may have to provide several fault determination networks to isolate failures that are not readily discernible by the computer.

Once the functional requirements of the control panel have been determined, the functional design, which is the second phase of the design process, is developed. Each aspect of the design process is, of course, strongly influenced by human engineering factors related to man/machine interfaces. The first item to be determined is the number of control panels required for the system. Multiple control panels can be considered when more than one operator is required, thus assuring more efficient system operation. With this approach, one panel might provide the primary operating mode functions and subordinate panels might provide strategy requests involving, for example, ramp metering or bus priority functions. The increased effectiveness of several panels would have to be compared to the increased operating cost of multi-operator configurations, the increased system interface wiring, control logic, memory storage and machine time involved in the inputting and outputting of data to and from more than one control panel before a recommendation could be made in this area. An evaluation of this type was conducted during Phase I of the UTCS program with the final recommendation for that program being a single control panel. This control panel, shown in Figure 4-11, includes the controls for the basic traffic system and the specialized critical intersection and bus priority operating functions.

The next phase is the design of the hardware configuration to implement the functions. Again, human engineering factors must be of prime consideration along with system cost. Several implementation schemes can be considered, covering a spectrum of approaches from a single switch or indicator for each function, to nested combinations of

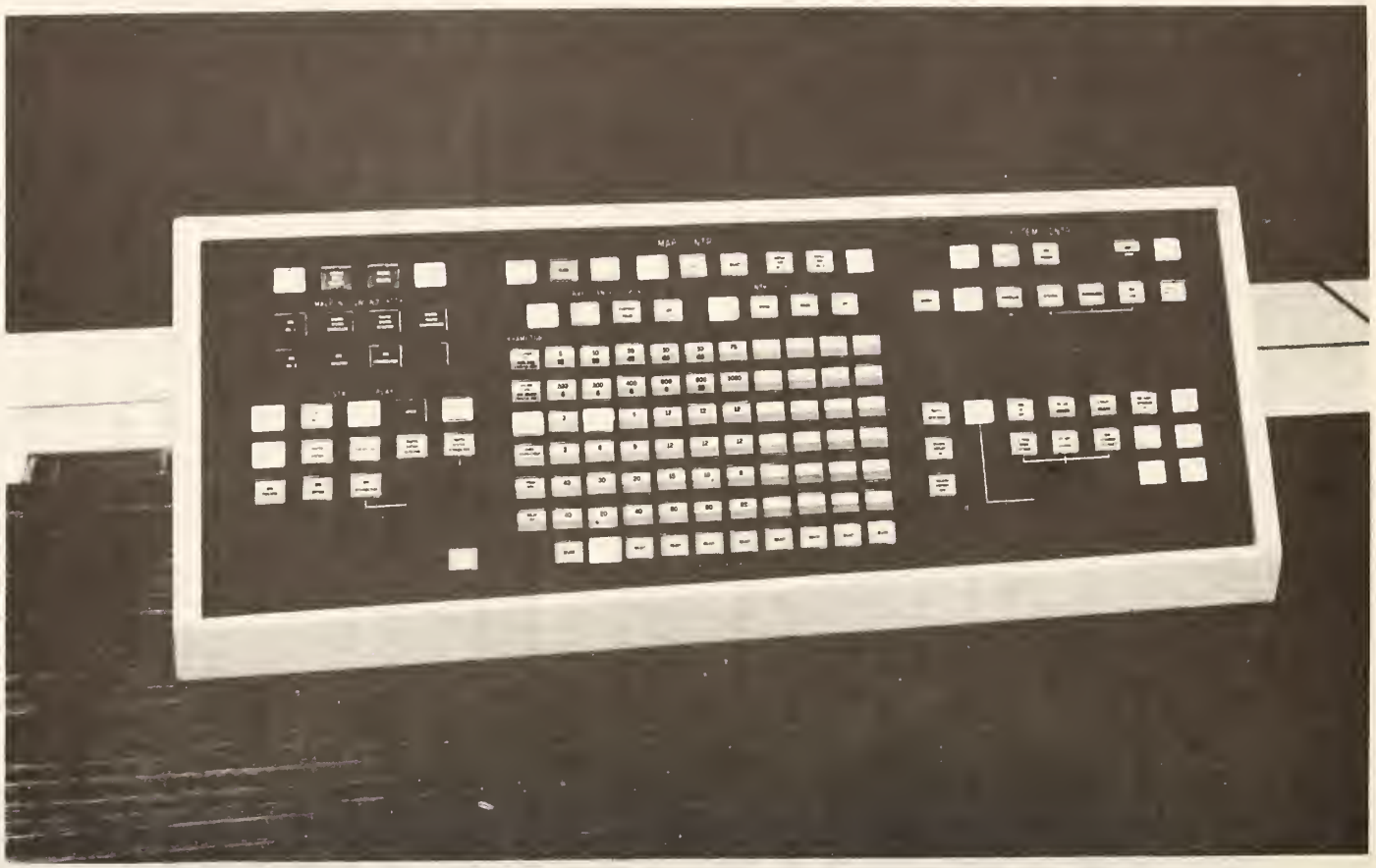

Figure 4-11. UTCS/BPS Control Panel

witches and indicators to define all of the system functions. Again referring to Figure -11, 129 switches and indicators were used in combination to generate all the possible ystem commands. If a single switch or indicator was assigned for the various functions, nore than 300 switches and indicators would have been necessary. The choice of a particular scheme is predicted upon the desired unit size, degree of versatility desired, and he obvious economic factors affecting the cost of the unit. Whenever the "switch combination" approach is employed, an additional tradeoff must be conducted to establish the best method for locking out erroneous operator commands by using either the computer or the control panel. This tradeoff must consider the additional programming and memory storage and machine time for error detection in the computer as opposed to hardware lockouts fabricated into the unit. Previous tradeoffs conducted in this area have indicated that hardware lockouts are more suitable. These hardware lockouts are implemented using holding coil or solenoid switches. These switches are unique in that they cannot be actuated unless a previously selected switch provides energization to the switch solenoid, a scheme similar to relay switching circuits where the relays are switched in a predetermined order. For example, the map control section of the Washington control panel, shown in the center section of Figure 4-11, has interlocked solenoid coil switches that will not permit the operator to request two conflicting displays simultaneously.

The results of the design phases described in the preceding paragraphs are then integrated with the more basic aspects of human engineering to establish a set of detailed requirements for the control panel. Since switches and indicators should be mounted, color-coded and identified for efficient selection and manipulation based on their proper functional relation, several layouts are generated and mock-up models are constructed for their study. After the selection of a particular layout, the basic geometry of the entire unit is defined to orient the displays so that parallax and glare are minimized and viewing distance, accessibility and illumination are optimized. The detailed hardware requirements are then established. These would include, as a minimum, specifications for the following:

- Lamp life
- Switch life
- Lettering legibility
- Switch form
- Surface viewing area

- Illumination
- Filter colors
- Switch or indicator repair or replacement method.

These requirements should reflect the feasibility of obtaining switches and indicators from several sources and should not dictate a custom-made or sole-source item.

The final phase of the design process is to establish the control panel electrical requirements. Since the timing of data transfer does not present any unusual problems, the primary concern is the cost to implement the control panel input/output functions. The cost of transmitting an individual discrete for each switch function to the computer input buffer must be compared to the cost of coding the control panel output and transmitting it to a smaller computer input buffer. Hardware coding can usually reduce the number of inputs by approximately 50 percent. For the several systems where this tradeoff has been conducted, the governing factor was the cost of the additional logic required to code the control panel outputs, thus dictating an individual discrete transmission be used. Finally, the remaining electrical requirements, such as signal levels, are determined from the computer interface specifications.

The ingredients required for the proper design of a traffic system control panel can be summarized as follows:

- Thorough knowledge of system functional requirements
- Understanding of the relationship between the operator and the traffic system
- Knowledge of human engineering factors as related to operator interface devices - particularly in the area of system control panels
- Solid background in hardware logic design with particular experience in the mechanization of computer input/output functions.

E. MAP Display Design

A properly designed traffic system graphic display will provide the system operator with real-time geographically related information in an easily recognizable map format. To ensure that the display provides this essential function, a thorough design investigation must be undertaken with such factors as clutter, ambiguity, recognition and

legibility being of prime concern. The steps in this design process are described in the succeeding paragraphs.

Before a display can be specified for a traffic system, one must first analyze the numerous techniques available for display fabrication to determine which best suits the technical requirements within the cost constraints. For example, the fabrication of the simplest type of display involves the custom mounting of catalogued components which are on a silk screened, engraved, or similarly diagrammed panel. The main advantage of this technique is that it is a relatively easy and low-cost method to fabricate displays. The main disadvantage is the difficulty in providing an effective tie-in between the panel components because the available sizes and shapes of catalogued indicators are necessarily limited. This approach, and more sophisticated techniques, should be examined to develop the optimum map display design for a specific traffic control system application.

The factors that influence the choice between display techniques are:

- Quantity of information to be presented
- Display size
- Graphic presentation method
- Illuminated indicators.

(1) Information Presentation

If, for example, the A phase or main street green display is the only information to be presented to the system operator, then the display indicators can receive their inputs directly from the communications equipment. The display of controllers under computer control can be derived from the same source. In addition, rudimentary sensor data can be displayed utilizing the outputs from the sensor communications equipments. In this instance, the illumination time and frequency of flashing of an individual sensor indicator would be related to the number of vehicles and speed at which the vehicles are stimulating a corresponding sensor in the system. However, with a large number of sensors, clutter becomes significant.

When display information beyond A-phase green and controller status is desired, then approaches other than adding indicators and interface cabling for each presentation can be considered. For example, an electronics unit was added to the Tampa and Washington

systems to interface the map display with the computer. The addition of this unit permitted the following information to be presented to the system operator(s).

Washington (UTCS) Display	Tampa Display
Controller status	Controller status
Controllers failed	Controllers failed
A-phase green return	A-phase green return
Bus priority system status	Sensors failed
Volume (VPH) at threshold levels	Volume (VPH) at threshold levels
Speed (mph) at threshold levels	Speed (mph) at threshold levels
Occupancy (%) at threshold levels	Occupancy (%) at threshold levels
Delay (sec) at threshold levels	Delay (sec) at threshold levels
Stops (stops/cycle) at threshold levels	
CIC status	
Queue (veh.) at threshold levels	
Bus passenger gain at threshold levels	
Buses helped at threshold levels	

The flexibility of this approach is extremely significant in that, once the display-to-computer interface has been established, virtually any type of system information can be presented to the system operator at the expense of additional programming.

(2) Display Size

The overall dimensions of the map display and the size of the indicators and legends are governed primarily by the required area coverage, location in the central site, and good human factors engineering relating to visual requirements. A comparison of the map display developed for the city of Tampa traffic system (Figure 4-12) and the map display developed for the Washington (UTCS) program (Figure 4-13) illustrates the difference that can influence display scales.

Figure 4-12. Tampa Traffic System Map

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Figure 4-13. Washington (UTCS/BPS) Traffic System Map

The area coverage and location in the central site of these displays were clearly specified. Both maps were to be approximately six feet by ten feet in size. The final design requirements for the traffic signal indicators and the link arrows were established as the result of studying numerous design variations. The conclusion for each case was that the traffic signal indicator would be shaped to depict the direction of traffic flow and would be illuminated green or red corresponding to the state of the A-phase green return.

Link indicators displaying traffic parameters at selected threshold would be positioned off the roadway and illuminated upon computer request. The Washington display had the additional requirement of displaying multiphase controller returns and link information for individual lanes at several of the intersections. For the Tampa display, the scale is 1 inch equals approximately 233 feet. In contrast, the Washington display required a scale of 1 inch equals approximately 150 feet, a scale about 30 percent larger than the Tampa unit. This larger scale was needed to display the amount of information required without clutter and ambiguity.

In addition, the link arrows on the Washington display were enlarged to 1 inch in length in contrast to the 1/2-inch arrows used on the denser Tampa display.

(3) Graphic Presentation

The graphic presentation on the map display must provide easily recognized indicators, legible but unobtrusive legends, familiar directional orientation, and clear street outlines. In addition, the map must be designed to minimize visual fatigue and also be understandable and aesthetically acceptable to visitors standing at some distance behind the operator's console.

The final selection of a particular graphic presentation technique requires a human engineering study of the numerous graphical techniques presently available or in the development stage. Several existing candidates are:

- Photographic enlargements of existing maps
- Enlargement of aerial photographs - This approach has been rejected in past design studies because trees and shadows and other miscellaneous items included in the photographs reduced the display legibility. Solutions to these problems are still being investigated.

- Custom artwork - This technique was employed for the Washington and Tampa displays since it permitted controlled manufacturing.

- Silk screened or anodized building blocks or tiles - Many of the displays fabricated to depict flow processes (e.g. refinery process control) use this approach. However, it appears that the approach is not economically feasible when the presentation depicts a large number of oblique and randomly interconnected points.

- Vinyl and tape compositions

- Plastic assemblies.

An additional factor to consider when selecting a graphic presentation is that the cost of a display is not primarily a function of the number of indicators but is instead a function of the area of the display surface and the display detail.

(4) Illuminated Indicators

As stated previously, the sizes of the indicators are governed by the identical constraints that determine the display size. The selection of an indicator to depict the status of the A-phase green return requires comparison of at least the following:

- One circular indicator at the center of each intersection

- One shaped indicator depicting direction at the center of each intersection

- Shaped indicators located at each link exit at an intersection.

The circular indicator is the most popular because a display can be fabricated economically with a single lampholder mounted at each intersection. The deficiency of the circle configuration is that it does not present the direction of the main street, and ambiguities result when such an indicator is used in the grid system which is characteristic of a central business district. This deficiency can be overcome with the addition of directional markings on a graphic presentation. A tradeoff would ascertain the economic advantage of fabricating a display with circular indicators and separate markings versus an alternate approach considering shaped indicators.

A shaped indicator, as previously suggested, eliminates the circle configuration deficiency without the clutter of additional markings at the intersections. The Tampa and

Washington displays were fabricated with single-headed and double-headed arrow-shaped indicators to depict direction of main street and one- or two-way traffic flow simultaneously.

The use of several shaped indicators to present A-phase green information at an intersection is not generally encouraged. However, if complex intersections that require particular attention exist in a system, then the shaped indicators described in the preceding paragraphs should be considered.

Link information (traffic parameters at selected thresholds) can be displayed either with additional indicators located off the roadway or by utilizing traffic signal indicators. The use of separate link indicators permits the simultaneous display of traffic signal and traffic parameter information. Sharing the traffic signal indicators permits only mutually exclusive display modes with the additional requirement that link information can only be displayed on a directional basis.

The concepts influencing the choice of the traffic signal indicators are also applicable to the selection of the separate link indicators.

The choice of illumination colors for the indicators does not present any particular problems. The traffic signal indicator is usually illuminated green corresponding to the A-phase or main street green. The non-green main street state can be depicted by a non-illuminated or red illuminated indicator. The easier-to-interpret red and green sequence on a single indicator is more difficult to implement. A back-lighting technique was developed for the Tampa and Washington displays, with two incandescent bulbs in a single custom lampholder providing the red and green illumination. Other experiments to achieve the red-green sequence with fiber optic light guides were not successful for the following reasons:

- Transmitted light was significantly attenuated due to the characteristic fiber optic end losses
- The end point of light was not sufficiently diffused, presenting a limited viewing angle
- Cost of special hardware.

New and promising illumination concepts can also be considered. Of particular interest are light-emitting-diodes (LED's) and shapes woven from fiber optic materials.

In summary, the logical steps in the design of a map display will involve:

- Complete definition of the information to be presented to the traffic system operator
- Definition of display size and scale based on the geographical area to be covered and the central site constraints
- Mode of graphic presentation based on aesthetic and cost considerations
- Indicator selection as to shape, color and positioning on the display.

4.2.2 UTCS/BPS DISPLAYS AND CONTROLS

The displays and controls selected for UTCS/BPS are as follows:

- Traffic control panel
- Two alphanumeric CRT's
- Illuminated map display
- Cross-reference directory
- Line printer
- Two TTY's.

The traffic control panel, CRT display units, and cross-reference directory are arranged on a table to form a control console (Figure 4-14). The control console is positioned so that all portions of the wall-mounted map display are visible from the operator's seated position(s). The line printer and TTY's are conveniently located relative to the traffic control console.

A. Traffic Control Panel

The traffic control panel portion of the console permits the operator to direct the operation of the system, and to select the type of information to be displayed. The panel layout (Figure 4-11) is the result of a human factors study which investigated alternative hardware types and arrangements. Emphasis of this study was on the placement of controls according to function, sequence of operation, frequency of use, and relationship to other equipment. The controls for the alphanumeric CRT are located on the left side of the panel.

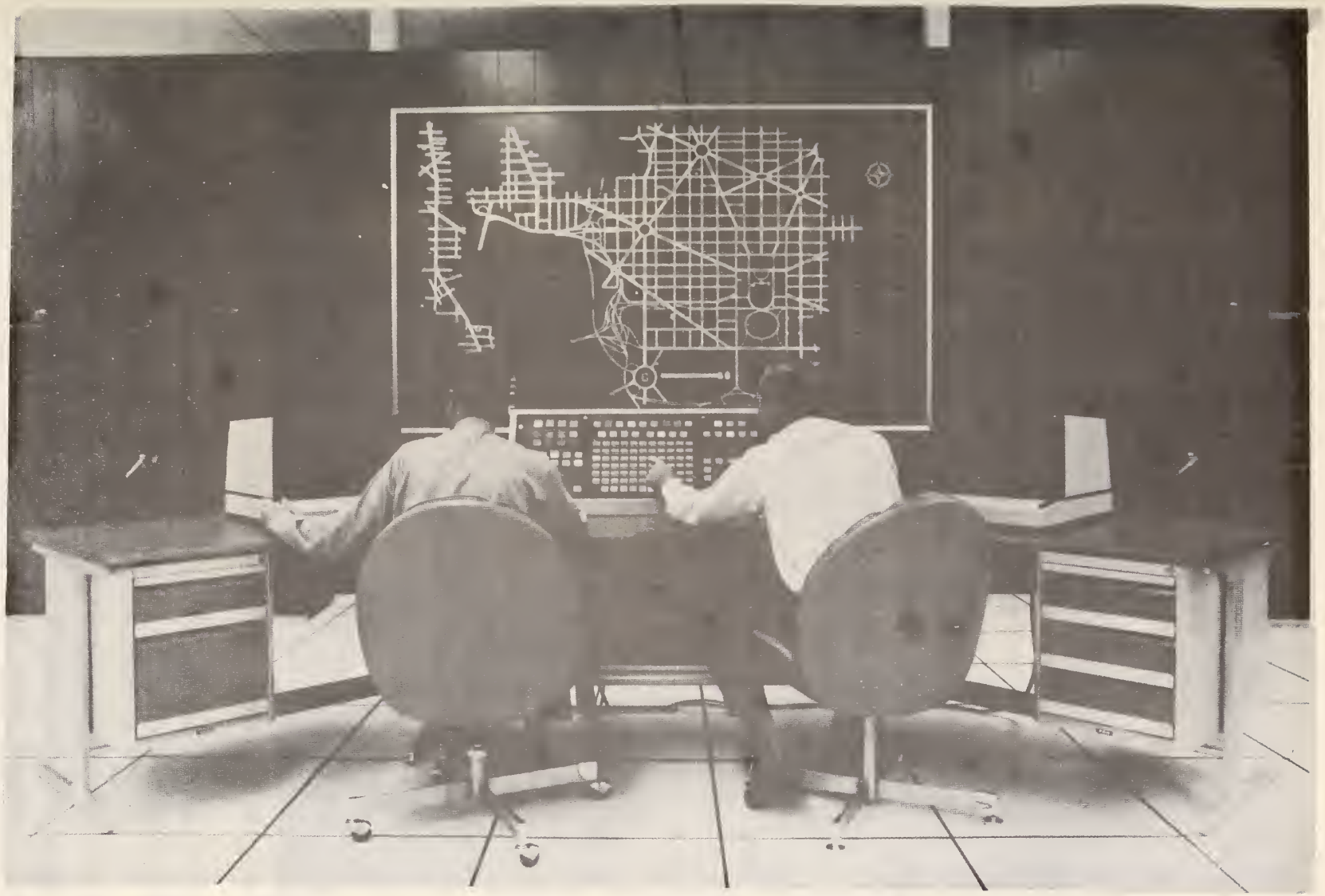

Figure 4-14. Traffic Control Console and Map Display

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The map controls are located in the center of the panel, and are thus close to the operator's line of vision to the wall map. The system controls are located on the right side, and the malfunction indicators on the left above the CRT controls.

Lighted pushbutton switches provide labeling of all selectable functions, and also provide illumination and color-coding of the functions which have been selected. These features permit quick response and positive visual indication of the action taken by the operator. Interlocking of the switches is performed by solenoids built into the switches themselves rather than by external circuits. In addition to the pushbutton switches, thumbwheel switches are included to provide a means of selecting 3-digit numerical quantities, and lamp indicators identical in appearance to the pushbutton switches are included to show results of computer action. (Alternative approaches using rotary switches and/or toggle switches, although less expensive, do not offer the ease of operation afforded by the illuminated pushbutton switches, and were rejected for this reason.) The lamp bulbs in the pushbutton switches and in the lamp indicators are replaceable from the front without the use of tools, and the legends are printed on a removable front lens so that they may be easily changed if required.

The traffic control panel is divided into four groups:

- System control
- Map control
- Malfunction indicators
- Status display

(1) System Control

The system control section, located on the right-hand side of the traffic control panel, is arranged in five levels. (See Figure 4-15.)

Level 1 permits selection of one of three functional groups of the total UTCS/BPS traffic system: Traffic Control, CIC, or Bus Priority.

Level 2 permits selection of the total system for the selected functional operation, or the appropriate subdivision of the total system. Inappropriate subdivisions are not permitted; for example, switch interlocking does not permit a bus zone selection on Level 2 in conjunction with a Traffic Control selection on Level 1.

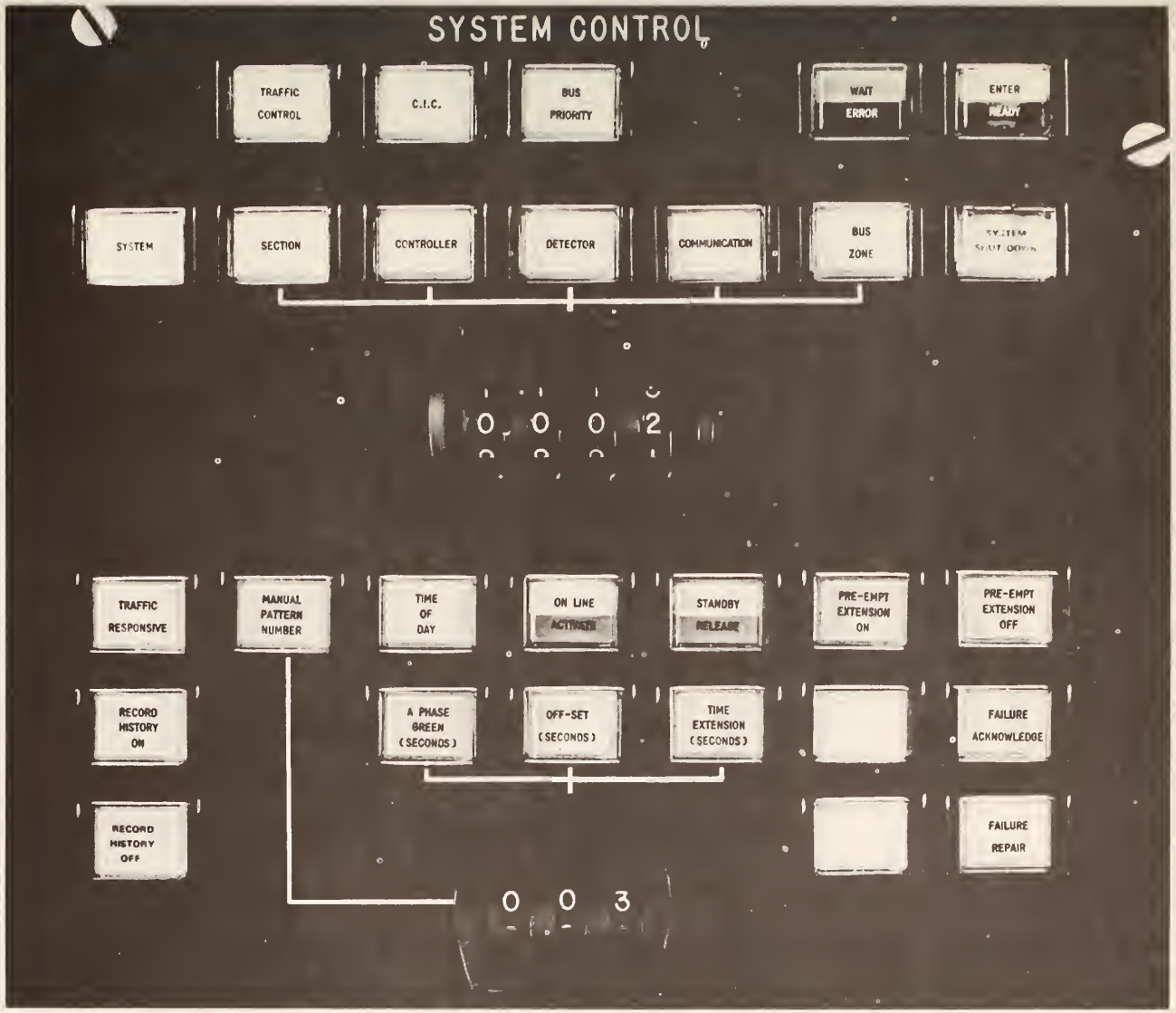

Figure 4-15. System Control Section

Level 3 consists of a 4-digit thumbwheel. As indicated by the white interconnecting lines on the panel, the thumbwheel setting is only appropriate in conjunction with a selection of Section, Controller, Detector, Communication, or Bus Zone.

Level 4 consists of seven pushbuttons of which only one selection is possible. If the selection is not appropriate and not consistent with selections on Levels 1 and 2, it cannot be implemented. For example, Manual Pattern could not be selected if the selection on Level 2 was Controller.

Level 5 consists of a 3-digit thumbwheel. As indicated by the interconnecting white lines on the panels, the thumbwheel setting is only appropriate with a selection on Level 4 of Manual Pattern, A-Phase Green, Offset, or Time Extension.

In the top right-hand corner of the panel, in line with the three Level 1 pushbutton switches, are two additional pushbutton switches; WAIT/ERROR and ENTER/READY. The ENTER/READY pushbutton must be pressed for each completed valid selection. If the selection is made without error, the bottom half of the ENTER/READY pushbutton will light up green after three seconds, indicating that the computer has accepted and will act upon the control panel request. If an error is made by the operator (for example, if he tries to place a specific controller on line that already has been under computer control) the bottom half of the WAIT/ERROR pushbutton will be illuminated red. This can be extinguished by depressing the pushbutton or by making another entry which is valid. The upper half of the WAIT/ERROR pushbutton (WAIT) is illuminated if, after a valid entry has been made, the computer determines that changes in the system are already in progress, such as a transition cycle, which may make unnecessary the need for the new operator change. The operator may thus be in a better position to judge at a later time if the change is really necessary. The computer will not honor the original request at a later time. The operator will have to re-enter the request if he so chooses. The WAIT light can be extinguished by depressing the WAIT/ERROR pushbutton, or by making another valid and accepted entry.

In all cases except one, a valid selection will require switch selections from 4 or 5 levels. The one exception is in the case of system shutdown. In this case the proper selection on Level 1 is Traffic Control in conjunction with the selection of System Shutdown on Level 2. The ENTER/READY pushbutton is then depressed, by passing other levels.

In Level 4 there are two pushbuttons, ON LINE/ACTIVATE and STANDBY/RELEASE, which have dual functions. The ON LINE and STANDBY portions of these switches are applicable only when TRAFFIC CONTROL is selected on Level 1. The top halves of

these switches light up accordingly when selected. If CIC or BUS PRIORITY is selected on Level 1, the bottom halves of these pushbuttons are applicable, that is, ACTIVATE and RELEASE.

(2) Map Control

The Map Control section, located in the center portion of the panel, is arranged in three levels. (See Figure 4-16.)

Level 1 permits selection of one of three functional groups of the total UTCS system: Traffic Control, CIC, and BPS.

Level 2 consists of two groups: Surveillance Display and Controller Display. A selection in the Surveillance Display group controls the link lights (orange and yellow arrows) in the map display and a selection in the Controller Display group controls the controller or intersection lights (red or green arrows). Appropriate selections from these two groups can be made simultaneously.

Three selections can be made on Level 2 regardless of the Level 1 selection as follows:

(1) Surveillance Display OFF - simultaneously with any Controller Display selection.

(2) Controller Display A-PHASE GREEN - simultaneously with any Surveillance Display selection.

(3) Controller Display OFF - simultaneously with any Surveillance Display selection.

Interlocking between Levels 1 and 2 prevents selections which are not appropriate. For example, FLOW DATA cannot be selected in conjunction with a CIC selection on Level 1.

Level 3 consists of a matrix of switches, six down and six across. Selection of one of six parameters and one of six threshold values for control of the link lights in the map display is possible. Level 3 is entered only when FLOW DATA is selected on Level 2.

The first two parameter switches in Level 3 have dual application. The top portions of the switches with the white background (OCCUPANCY and VOLUME) are applicable for a TRAFFIC CONTROL selection on Level 1. The button portions of the

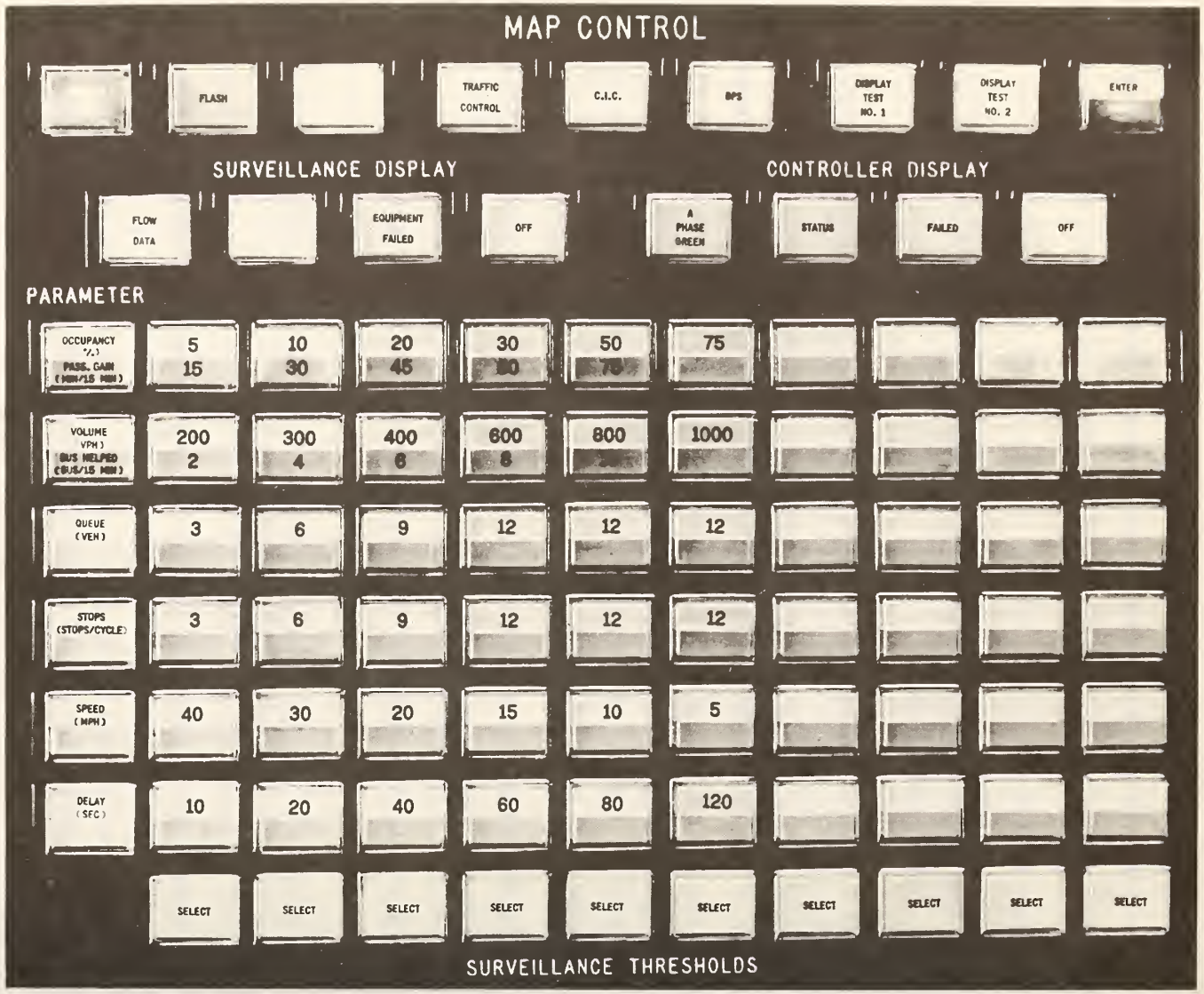

Figure 4-16. Map Control Section

switches with a yellow background (PASSENGER GAIN and BUSES HELPED) are applicable for a BPS selection on Level 1.

The ENTER/READY pushbutton is located in the upper right-hand corner of the Map Control section. The bottom half of the switch, when depressed, will light up green within three seconds, indicating that the request has been accepted by the computer. The computer will process Surveillance Display and Controller Display selections simultaneously, that is, the ENTER/READY pushbutton need be depressed but once. The appropriate selections are as follows:

Level 1 Selection	Surveillance Display	Controller Display
Traffic Control	Flow Data or Failed	Failed or Status
BPS	Flow Data or Failed	Status
CIC	Not Applicable	Status

Other pushbutton switches in the Map Control group are located on the top of the panel in line with the Level 1 switches. These switches operate independently of the computer and do not require that the ENTER/READY pushbutton be depressed. These switches and their functions are as follows:

DISPLAY ON-OFF - A pushbutton (green background) that turns the power to the Map Display on or off when depressed.

FLASH - A pushbutton (yellow background) that causes the link lights being displayed on the map to flash on and off when depressed. The lights flash when the switch light is on. The use of the flash mode is a matter of operator preference. It can be useful in highlighting the link lights in a background of controller lights.

DISPLAY TEST #1 AND DISPLAY TEST #2 - These two pushbuttons (yellow backgrounds) are used to test whether any of the Map Display lamps are inoperative. Display Test #1 is in effect when DISPLAY TEST #1 pushbutton is depressed (illuminated). In order to put Display Test #2 in effect, DISPLAY TEST #1 pushbutton must be depressed again (lamp out), and then depress DISPLAY TEST #2. Details as to which lights are encompassed by tests 1 and 2 are given in paragraph 4.2.2 B(6) Map Display Lamp Tests.

(3) Malfunction Indicators

There are seven lamp indicators (red backgrounds) which are located in the upper left hand portion of the panel (Figure 4-17). These are:

(1) CPU #1

(2) CPU #2

(3) TRAFFIC SYSTEM CONTROLLER

(4) TRAFFIC SYSTEM DETECTOR

(5) TRAFFIC SYSTEM COMMUNICATION

(6) BPS DETECTOR

(7) BPS COMMUNICATION

The system continuously monitors system components, including its own CPU's. If a malfunction is indicated, the computer sends to the panel a signal which lights the appropriate indicator.

The panel looks for a change of state from CPU #1 every two seconds. If it does not occur, signifying that the computer is not functioning normally, the CPU #1 malfunction light will be turned on. If a failure is detected in CPU #1, the UTCS is placed in standby (all controllers are released from computer control). In addition, the panel looks for a discrete signal from the computer which is indicative of CPU #2 status. If a failure is detected in CPU #2, the UTCS continues to operate. However, all BPS operation is released.

For the other malfunctions, the red light remains on until the operator acknowledges the failure by making the appropriate entry in the System Control section of the panel.

Above the malfunction indicators are located four pushbuttons as follows:

(1) PANEL ON-OFF

(2) DISABLE FAULT RELEASE

(3) MANUAL RELEASE

(4) ALARM DISABLE

The PANEL ON-OFF pushbutton, which has a green background, turns power on and off to the panel. The DISABLE FAULT RELEASE pushbutton, which has a red background, will

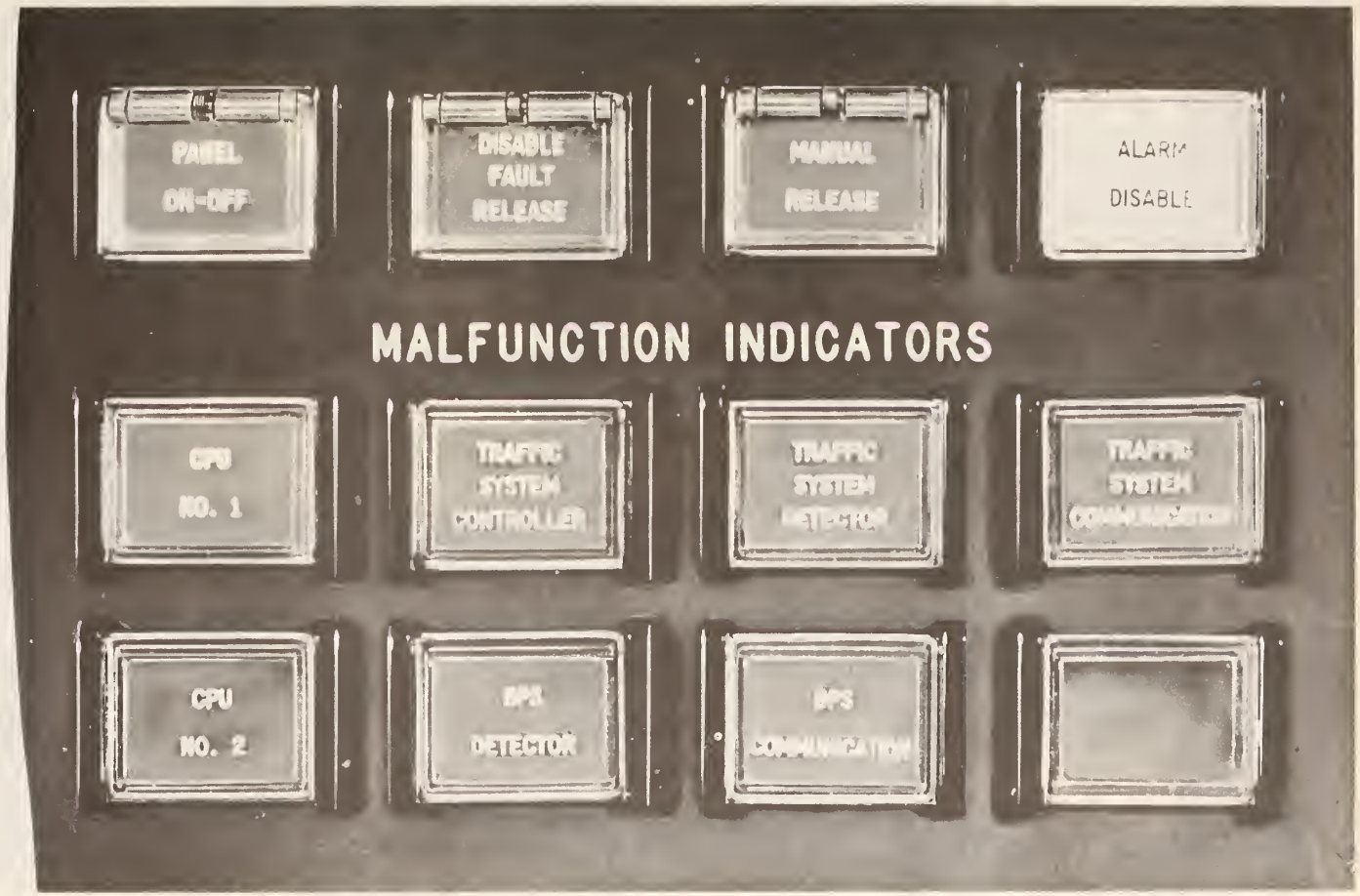

Figure 4-17. Malfunction Indicator Section

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inhibit the dropping of the system into standby due to the detection of a CPU #1 fault when it is depressed (light on). This pushbutton is used only when it is known by the operator that the CPU #1 malfunction indication is due to the circuitry from the computer to the panel light, and not due to the CPU itself. This will permit normal system operation by overriding the fault release which would otherwise occur. The MANUAL RELEASE pushbutton, which has a red background, will release all controllers to local control when depressed (light on). The operator uses the MANUAL RELEASE if he determines that the system is operating abnormally and it may not be possible to place it in standby by using a System Function entry on the panel. The ALARM DISABLE pushbutton, which has a yellow background, will inhibit the audible alarm when depressed (light on). If the light is off, a failure detected in any one of the possible malfunctions (except CPU #2) will cause the audible alarm to turn on. The alarm can be turned off by depressing the switch (light on). While the light is on, any subsequent malfunctions will not cause the audible alarm to turn on.

Three of the above switches (PANEL ON-OFF, DISABLE FAULT RELEASE and MANUAL RELEASE) are guarded switches. They require that the guard be lifted in order to depress them. The guards were included to prevent the operator from depressing these critical switches inadvertently.

(4) Status Display

The Status Display section, located in the lower left hand portion of the panel, is arranged in three levels (Figure 4-18).

Level 1 permits selection of CRT #1 or CRT #2, located on the left and right side of the console table, respectively.

Level 2 permits selection of one of seven possible display pages, including both the Traffic System and the BPS System. These are as follows:

Level 2 Switch Selection	Display Page
TRAFFIC SYSTEM FAILURE	Failure Status
TRAFFIC SYSTEM	System Status
CONTROLLER	Controller Status
TRAFFIC SYSTEM DETECTOR	Detector Status

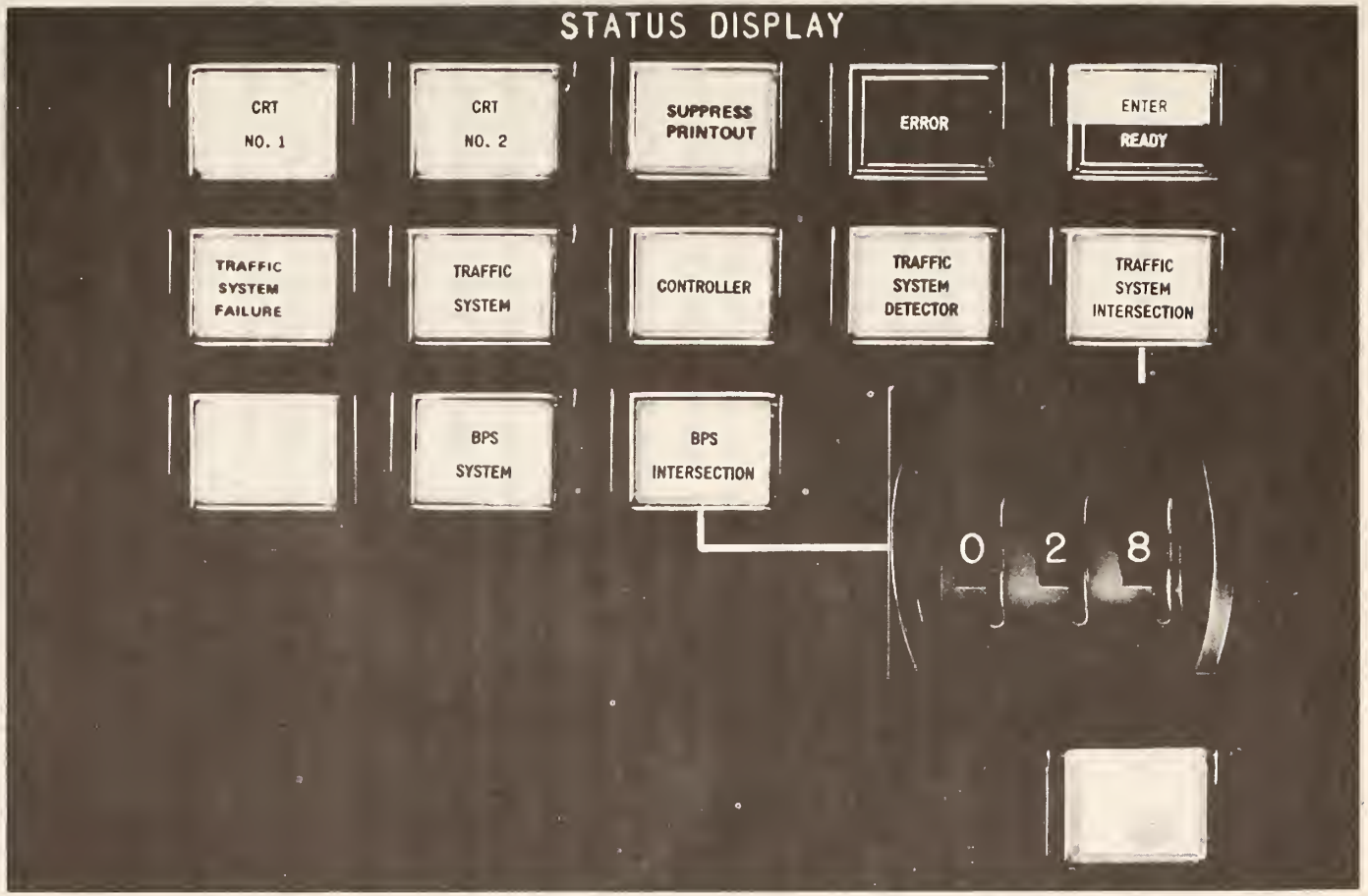

Figure 4-18. Status Display Section

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Level 2 Switch Selection	Display Page
TRAFFIC SYSTEM INTERSECTION	Intersection Status
BPS INTERSECTION	BPS Intersection
BPS INTERSECTION	BPS Intersection Status

Note that the Failure Status page includes BPS failures as well as Traffic System failures. Details of these pages are given in Appendix C.

Level 3 consists of a 3-digit thumbwheel. As indicated by the interconnecting white lines on the panel, the thumbwheel setting is only appropriate with a selection on Level 2 of TRAFFIC SYSTEM INTERSECTION or BPS INTERSECTION.

In line with Level 1 are three additional pushbuttons: ENTER/READY, ERROR, and SUPPRESS PRINTOUT. ENTER/READY must be depressed for each valid selection. If the selection is made without error, the bottom half of the ENTER/READY pushbutton will light up green after three seconds, indicating that the computer has accepted and will act upon the control panel request. If an error is made by the operator (for example, if he entered an invalid intersection number) the ERROR light would be turned on by the computer. The ERROR light can be extinguished by depressing the pushbutton or by making another valid entry. The SUPPRESS PRINTOUT pushbutton, when depressed (light on), will inhibit the printout of the 15-Minute Report. It will not inhibit the End of Day Report upon system shutdown, however.

A CRT display page can be obtained on either or both CRT units. Any of the seven possible displays can be obtained on a CRT, with any one of the remaining six displays on the other CRT. Entry or change of a CRT display can only be made one at a time, however.

(5) Simultaneous Control Panel Entries

If each of the three possible panel selections is entered separately (System Control, Map Control, and Status Display) it will be three seconds before there is an indication that the computer has serviced the request. The three second delay may be longer if more than one ENTER pushbutton is depressed simultaneously. System Control requests are serviced first, then Map Control requests, and finally Status Display requests. Consequently, if a System Control request is entered before the computer has started to process a lower priority request, the System Control request will be honored first, thus delaying the servicing of the lower priority request by at least three seconds.

(6) Valid Control Panel Entries

Valid panel entry combinations for System Control, Map Control, and Status Display are summarized and tabulated in Appendix B.

B. Map Display

The map display graphically illustrates the traffic signals, traffic parameters, and equipment status for the area of Washington, D.C. which is controlled by the UTCS/BPS instrumentation. The map display and its associated electronics operate in conjunction with the control panel and the computer. The map also operates directly, in conjunction with signals from local controllers and the District's radio link, when the computer is off-line (computer in standby).

(1) Display Arrows

Three types of arrows are used: intersection arrows, link arrows (including through and turning), and large one-way arrows on 15th and 17th Streets. The intersection arrows, indicative of controller operation and status, are illuminated green or red; the link arrows are illuminated both yellow and orange. The yellow arrows are mostly directed west and north while the orange arrows are directed east and south. The large arrows on 15th Street (pointing north) and 17th Street (pointing south) are illuminated green by signals from the District's radio link, which indicate when these streets become one-way. The 15th Street arrow is illuminated during the PM peak hours, and the 17th Street arrow is illuminated during the AM peak hours.

(2) Display Legend and Operation

The legend indicating the possible display modes is located in the lower right-hand corner of the display. A summary of the various legends, together with the operation of the intersection and link arrows, is given in Table 4-4.

(3) A-Phase Green Operation

In the A-phase green (AØ Green) mode, the intersection arrows are controlled by the A-phase green return signals from the controllers. In addition, the large one-way green arrows are controlled by signals from the District's radio link. This mode is in effect when the computer is in standby (indicated by the legend on the map display), or when the A-phase green mode is selected via the map display control when the computer is on line. When in this mode, all of the legends concerned with controllers or intersection

lights are turned off. These include Controller Status, CIC Status, BPS Controller Status and Controllers Failed.

(4) Simultaneous Operation of Intersection and Link Arrows

Any one of the six possible intersection display modes can operate sinultaneously with any one of the ten link display modes. (Refer to Table 4-4.) Two legends on the map will accordingly be illuminated, except for the case where the A-phase green mode is selected for the intersection display. In this case, only the link display legend is illuminated.

(5) Early Warning Link Arrows

There are twelve early warning link arrows dispersed beyond the periphery of the UTCS network on the map display. These are links which are instrumented with single detectors. The applicable display modes for these links are: Occupancy, Volume, Speed, and Surveillance Equipment Failed.

(6) Map Display Lamp Tests

Map display lamp tests are made directly from the control panel, independently of computer operation. There are two tests: Display Test 1 and Display Test 2.

Display Test 1 illuminates the following:

(1) Intersection arrows red

(2) East and north directed link arrows

(3) Test legend green

Display Test 2 illuminates the following:

(1) Intersection arrows green

(2) West and south directed link arrows

(3) All legends (green or red)

(4) One-way arrows green

TABLE 4-4. MAP DISPLAY LEGEND AND OPERATION

Legend	Operation of Arrows	Threshold Applicability	Legend Illumination
Occupancy	Link arrows illuminate in correspondence with traffic system links. *	Links for which the selected threshold on the control panel are exceeded are illuminated.	Green
Volume	Same as above	Same as above	Green
Speed	Same as above	Links for which the speed is less than the selected threshold are illuminated.	Green
Queue	Illuminates only link arrows which correspond to Q-instrumented links.	Same as for occupancy	Green
Stop	Same as for queue above	Same as for occupancy	Green
Delay	Same as for queue above	Same as for occupancy	Green
Passenger Gain	Link arrows illuminate in correspondence with bus zones.	Bus zones for which the passenger gain is less than the selected threshold are illuminated.	Green
Buses Helped	Same as for passenger gain.	Bus zones for which the buses helped is less than the selected threshold are illuminated.	Green

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*The queue-instrumented (multi-detector) link is displayed when there is more than one link in a given direction which includes a queue link.

TABLE 4-4. MAP DISPLAY LEGEND AND OPERATION (Cont.)

Legend	Operation of Arrows	Threshold Applicability	Legend Illumination
CIC Status	Intersection arrows for controllers activated (green) and those not activated or inhibited (red).	Not applicable	Green
Controller Status	Intersection arrows for controllers on-line (green) and those in standby (red).	Not applicable	Green
BPS Controller Status	Intersection arrows for controllers activated for bus priority operation (green) and those not activated or inhibited (red).	Not applicable	Green
Surveillance Equipment Failed	Link arrows illuminate in correspondence with traffic system links which have a detector or communication failure.	Not applicable	Red
BPS Surveillance Equipment Failed	Link arrows illuminate in correspondence with BPS zones which have a detector or communication failure.	Not applicable	Red

TABLE 4-4. MAP DISPLAY LEGEND AND OPERATION (Cont.)

Legend	Operation of Arrows	Threshold Applicability	Legend Illumination
Control-lers Failed	Intersection arrows for controllers which have failed (red) and non-failures (green).	Not applicable	Red
Computer in Standby	Not applicable	Not applicable	Illuminated red if computer is not on-line.
Threshold	Not applicable	Legend for 4-digit threshold	Not illuminated
Threshold Digits	Not applicable	4 digits, correspond to threshold selection in applicable display modes.	Green
Test	Display Test 1 ON. Intersection arrows illuminate red and half of link arrows are illuminated.	Not applicable	Green
(All On)	Display Test 2 ON. Intersection arrows illuminate green and other half of link arrows are illuminated.	Not applicable	All legends illuminated red and green as applicable.

C. CRT Display Units

Original specifications called for two CRT's, one to be dedicated to UTCS functions and the other to BPS functions. The units have been integrated so that either one can be used to display UTCS and BPS functions simultaneously. This arrangement has the advantage of permitting two UTCS or BPS displays to be viewed simultaneously, or a UTCS display together with a BPS display.

The two CRT's operate in conjunction with the control panel and the computer to present the desired System, Intersection, and Failure Status pages. The computer paints and updates the displayed pages upon control panel request, based on its stored memory of system configurations. The computer updates the displayed data once every 25 seconds.

(1) Equipment Description

The display unit consists of a 12-inch TV monitor tube, a keyboard and its associated electronics. Alphanumeric characters are illuminated in accordance with coded inputs from the computer. Controls on the front panel, located behind the keyboard, are similar to those of a commercial TV receiving set. The controls are as follows: BRIGHTNESS, HORIZONTAL HOLD, POWER ON-OFF, VERTICAL HOLD and CONTRAST. The control settings are quite stable and, once set, do not require adjustment in normal operation. On the rear of the display unit chassis are a MODE switch and a BAUD RATE switch which are set to match the interface mode and speed for communication with the computer. The settings of these switches are fixed and are as follows:

MODE-Full

BAUD RATE-2400

The keyboard is not used in normal system operation. It is utilized in troubleshooting CRT display unit malfunctions.

(2) CRT Display Pages

There are seven CRT display pages:

(1) Failure Status

(2) System Status

(3) Controller Status

(4) Detector Status

(5) Intersection Status

(6) BPS System Status

(7) BPS Intersection Status

Typical display pages for the seven types are presented in Appendix C.

D. Cross Reference Directory

The Cross Reference Directory, located on the control console table, lists all controllers, vehicle detectors, bus detectors, and associated electronics by number and/or street location. It provides information required by the traffic system operator to permit the selection of a particular controller or detector on the control panel, and to exchange information with central and field maintenance personnel in pinpointing and correcting system malfunctions.

The directory consists of a file of 3 in. x 5 in. cards mounted in a Rolodex file index. Cards are mounted on two drums which are independently controlled by external knobs on the left and right side of the file cabinet. The file is composed of four card types which are illustrated in Figures 4-19 through 4-22. The file cards are for vehicle detector electronics units, bus detectors, field cabinets (CB), and electronics cabinets (EB). Complete sets of each of the four types of cards are mounted on the left- and right-hand drums. However, they are ordered differently on the two drums to permit greater flexibility and ease in locating the required information. A breakdown of the filing configuration of the left- and right-hand drums is given in Table 4-5.

A discussion of the formats of the four types of file cards is provided in the following paragraphs.

(1) Vehicle Detector Electronics Units File Card

The sample card, Figure 4-19, indicates that the receiver for detector number 253/190 is located in CB 57. The detector has a Q3 function in the system which means that it is the third detector of a multi-detector link located approximately 385 feet up-stream from the stop bar (Figure 3-9). The associated link number (63) is referenced in the

TABLE 4-5. CROSS REFERENCE DIRECTORY FILE CONFIGURATION

Card Type	Left Hand Drum	Right Hand Drum
Vehicle detector Electronics units	Filed in order of number on field drawing	Filed in order of computer number
Bus detectors	Filed in order of number on field drawing	Filed in order of computer number
Field cabinets (CB)	Filed in alphabetical order of street location	Filed in order of cabinet number
Electronics cabinets (EB)	Filed in alphabetical order of street location	Filed in order of number on field drawing

computer and appears on the CRT displays and printed reports. Note that the controller associated with detector 253/190 is CB 54, although the detector electronics are located in CB 57. An inspection of the UTCS Installation Drawing 4200, Sheet 15, which is referenced on the card, will disclose that vehicles sensed by this detector will affect the downstream intersection, or the controller at 18th Street and Pennsylvania Avenue (CB 54). In the majority of cases, however, detector electronics are located in CB's with their associated controller.

The location of the detector receiver and transmitter modules in the controller cabinet, as well as the location of its associated receiver module in Central are specified on the card by an alphanumeric code. (See Field Cabinet Wiring Lists for the UTCS/BPS Program in Reference 6C, for details on the interpretation of the code for determining the physical location of the modules.)

(2) Bus Detector File Card

The sample card, Figure 4-20, indicates that the receiver for bus detector number 1/144 is located in CB 123 which is also its associated CB. The detector has a B2 function in the system which means that it is the upstream detector of associated bus zone number 72. The detector is located about 195 feet upstream from the stop bar. Other data and references on the bus detector card are similar to those given on the vehicle detector electronics unit cards.

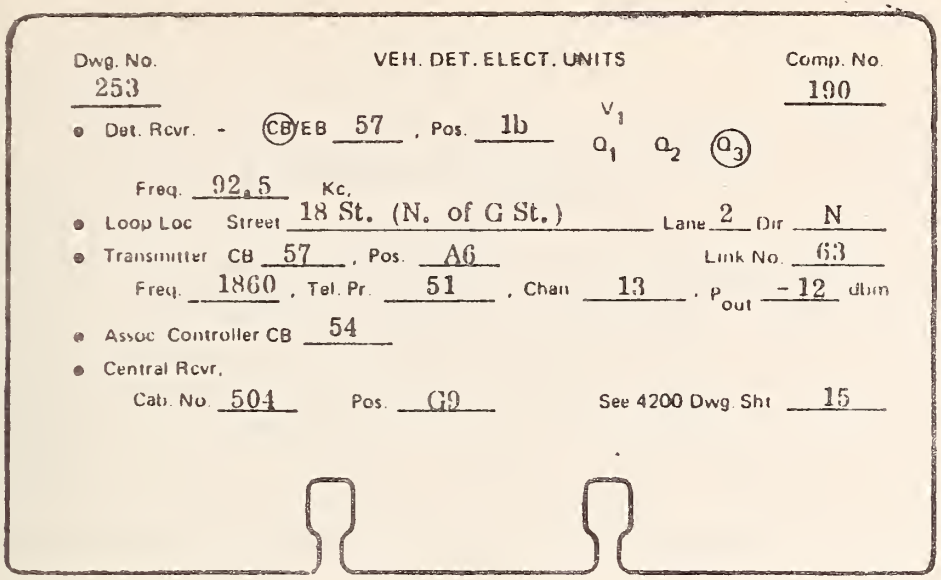

Dwg. No.
253
VEH. DET. ELECT. UNITS
Comp. No.
190
Det. Rcvr. - CB/EB 57 , Pos. 1b
V1
Q1 Q2 Q3
Freq. 92.5 Kc,
Loop Loc Street 18 St. (N. of G St.) Lane 2 Dir N
Transmitter CB 57 , Pos. A6 Link No. 63
Freq. 1860 , Tel. Pr. 51 , Chan 13 , Pout -12 dbm
Assoc Controller CB 54
Central Rcvr.
Cab. No. 504 Pos. G9 See 4200 Dwg. Sht 15

Figure 4-19. Sample Vehicle Detector Electronics Units File Card

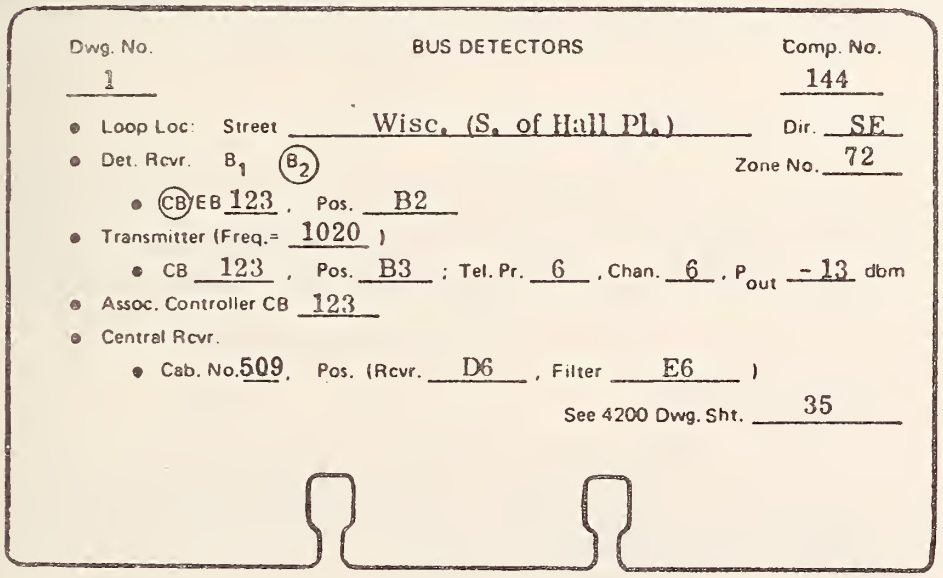

Dwg. No.
1
BUS DETECTORS
Comp. No.
144
Loop Loc: Street Wisc. (S. of Hall Pl.) Dir. SE
Det. Rcvr. B1 B2 Zone No. 72
CB/EB 123 , Pos. B2
Transmitter (Freq.= 1020)
CB 123 , Pos. B3 ; Tel. Pr. 6 , Chan. 6 , Pout -13 dbm
Assoc. Controller CB 123
Central Rcvr.
Cab. No. 509, Pos. (Rcvr. D6 , Filter E6)
See 4200 Dwg. Sht. 35

Figure 4-20. Sample Bus Detectors File Card

E. Field Cabinets (CB) File Card

The sample card, Figure 4-21, lists and describes the equipments mounted in the field cabinets or CB's. Data are listed on both the front and back of the card. The controller type is denoted by a 3-number code. The first number can be either 19 or 40, which indicates the number of circuits available on the cam stacks. The second number can be either a 1, 2, or 3; these designations indicate that the CB is adapted for a full complement, partial complement or none of vehicle and bus detector electronics modules, respectively. The third number can be either 16 or 18, which indicates the total number of cam segments available on each circuit. All vehicle and bus detectors located in the CB are listed on the front of the card by field drawing number. (Refer to vehicle detector or bus detector card file to obtain the related computer numbers.) If the CB complement includes vehicle or bus detector transmitters only (associated receivers located remotely), they are so indicated.

The back of this lists the A-phase and minor-phase green transmitters used in the controller, that is, the main street green (MSG) 1 (A-phase) with MSG 2 and 3 (minor phases), as required, together with their frequency, telephone pair used, and the location of their associated reeeivers in Central. Also on the back are the hold and advance receiver frequency and location information within the CB, plus the location of the associated transmitter at Central. Vehicle and bus detectors which are associated with the controller (#57), but are located remotely, are also listed on the back of the card.

F. Electronics Cabinets (EB) File Card

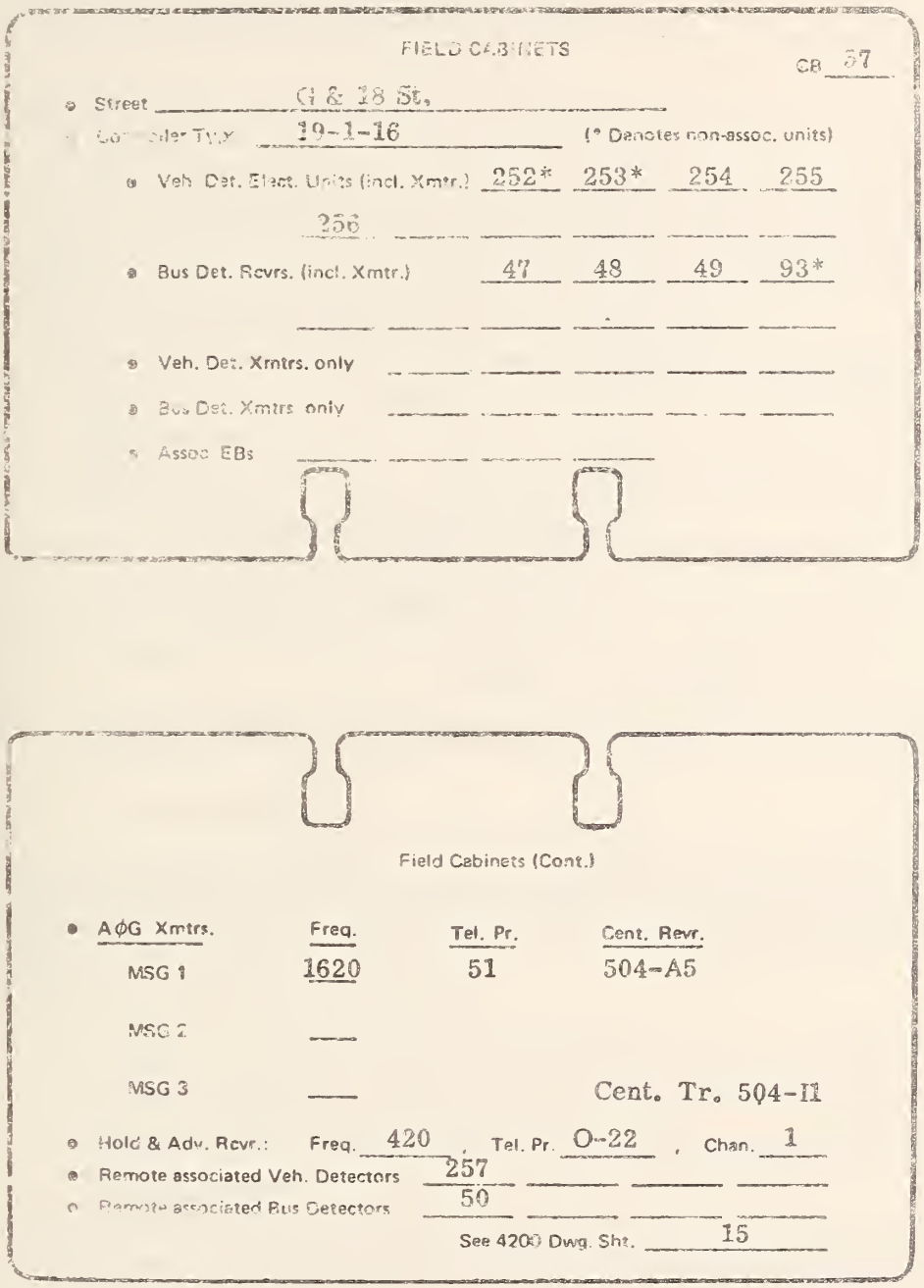
The sample card, Figure 4-22, lists by field drawing number the vehicle detector and bus detector electronics, which are housed in the electronics cabinets. (Refer to vehicle detector and bus detector card file to obtain the related computer numbers.) Also listed is the controller associated with the EB equipment eomplement.

G. Line Printer Report

The operation and use of the Line Printer in the UTCS/BPS system were previously described. Refer to Appendix C (Status Reports and Displays) for a discussion of sample UTCS/BPS 15-Minute and End of Day Reports.

H. Teletypewriter Reports

The operation and use of the UTCS/BPS TTY's were previously described. The TTY's are not used to print out traffic-related reports, but rather to print out messages



FIELD CABINETS

CB 57

- Street: G & 18 St.
- Controller Type: 19-1-16 (* Denotes non-assoc. units)
- Veh. Det. Elect. Units (incl. Xmtr.): 252* 253* 254 255 256
- Bus Det. Rcvrs. (incl. Xmtr.): 47 48 49 93*
- Veh. Det. Xmtrs. only
- Bus Det. Xmtrs only
- Assoc EBs

Field Cabinets (Cont.)

• AØG Xmtrs.	Freq.	Tel. Pr.	Cent. Rcvr.
MSG 1	1620	51	504-A5
MSG 2			
MSG 3			Cent. Tr. 504-I1

- Hold & Adv. Rcvr.: Freq. 420, Tel. Pr. O-22, Chan. 1
- Remote associated Veh. Detectors: 257
- Remote associated Bus Detectors: 50

See 4200 Dwg. Sht. 15

Figure 4-21. Sample Field Cabinets (CB) File Card (Both Sides)

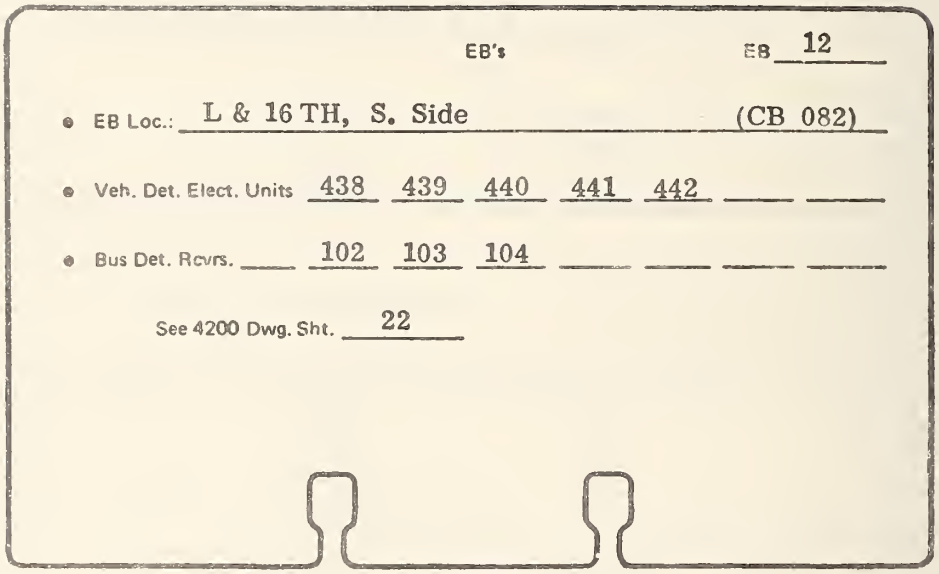


Figure 4-22. Sample Electronics Cabinets (EB) File Card

concerned with the operation of the UTCS/BPS program and the computer peripheral equipments.

4.3 CENTRAL SITE INSTALLATION AND DESIGN

4.3.1 GENERAL

The computer, peripheral equipment, communications, and all other apparatus required to direct operation of either the prime or back-up system will be housed in a room designated the Traffic Control Center. Installation of equipment in this room requires consideration of the following design aspects (refer to Appendix D):

- Equipment layout for functional, structural, interconnection, and aesthetic requirements
- False flooring for cable routing purposes
- Temperature and humidity conditioning
- Acoustics, which will be designed as for a standard industrial office
- Lighting, which will designed as for a standard, shadowless industrial office
- Power requirements.

The design and layout of the central site are initiated after the system component configuration has been defined. The procedure for generating the final installation drawings and specifications require the following steps:

1. Catalog the physical characteristics of all system components including support equipment. The required data include: overall dimensions, clearances, weight, power requirements, heat dissipation, and air circulation requirements.
2. Make a scaled layout of equipments, giving full consideration to human engineering factors.
3. Provide the planning engineering to determine the overall power, air conditioning, lighting, construction, and acoustical requirements.

4. Make detailed installation drawings indicating final construction details, including floor, walls and ceiling construction, cable installation, temperature and humidity conditioning equipment, lighting installation, power, and telephone installation.

4.3.2 RECOMMENDED SPACE AND ENVIRONMENTAL CHARACTERISTICS

The following paragraphs present recommended space and environmental characteristics which should be reflected in the design of the central site.

A. Site Selection

Size - The proposed area should be large enough to accommodate the planned system and all future expansion of equipment. Allowance should be made for obstructions that will have an effect on equipment location such as walls, pillars, doors, aisles, etc.

Location - The proposed area should be sufficiently close to all support areas, which normally include:

- Maintenance room
- Card and tape storage rooms
- Tabulating equipment room
- Programmers' offices
- Supervisory offices
- Air conditioning equipment room.

Traffic patterns and work flow between these areas should also be considered.

Delivery Route - Doors, elevators, corridors, etc., should have strength and clearance necessary for moving the individual units of the system to the site.

Raised Floor - A "free access" type raised floor is required for installation of computer systems to facilitate routing of inter-cabinet electronic cables from the computer to the various peripheral units and to allow routing of power wiring to all units requiring user-furnished primary power. The raised floor must meet the following requirements:

Uniform Loading

150 pounds per square foot with a maximum deflection of 0.01 in.

Concentrated Load

1,000 pounds on any square inch, with a maximum deflection of 0.10 in

Construction

Grid construction with panel seams located over the stringers. Panels shall have no exposed metal edges. Panel size is optional, but it is recommended that panels smaller than 18 in. x 18 in. or larger than 36 in. x 36 in. not be used.

Clearance

A minimum of 7 in. is required between the primary floor and the support stringers. However, it the plemun is to be used for both cooling and cabling, the clearance should be increased to 12 in. to reduce the possibility of obstructing the air flow.

Vibration - The vibration in the computer area must be negligible. Reliability of the system is seriously degraded by sustained vibration or periodic shock.

Code Restrictions - Local codes should be checked to ensure compliance with all governing codes regarding building construction, air conditioning, electrical wiring and fire protection requirements.

B. Computer System Layout

The following factors contribute to an optimum layout:

(1) Wall Construction

The computer area should be enclosed by walls on all sides, from structural floor to structural ceiling, with entrances and fire exits as required. Existing wall structures are utilized wherever possible in determining the system layout plan. All walls and partitions should be of a non-combustible material that has a flame-spread rating of 25 or less. The fire-resistance rating of the walls will depend on the exposure to other areas, but should not be less than one hour.

(2) Floors

The floor upon which the computer will be located must be capable of supporting the equipment weights which have been cataloged. It is recommended that areas with wooden floors not be selected as sites for the computer system, for fire prevention reasons. The primary floor should be sealed or painted for control of dust.

(3) Extra Support Pedestals

Extra support pedestals are to be provided for installation under all heavy equipment installed on the raised-floor. The computer manufacturer's installation planning representative will specify the number and location of these pedestals.

(4) Floor Covering

The raised floor in the computer area shall be covered with a floor covering for purposes of dust circuit, secure footing, and maintenance. Floor covering material may be of the following types:

- Tile - Any of the various types of tile or linoleum may be used in the computer area. Covering material should be chosen for its appearance, ease of upkeep and resistance to cracking. Vinyl or asbestos tile is preferred because of its resilience and resistance to cracking.

- Carpeting - If carpeting is used in the computer area, it should be of a commercial grade chosen on the basis of quality, wear resistance and ease of upkeep. All carpeting in computer areas must be of a type which will prevent static buildup, or must be suitably treated.

C. Ceiling

(1) Structural

The structural ceiling in the computer area should be watertight to reduce the possibility of water damage to the equipment caused by water seepage from the floor above.

(2) Suspended Ceiling

It is recommended that an acoustical ceiling be installed in the computer area to aid in reducing the noise level and to enhance the appearance of the area. The ceiling

plenum may also be used for a return air plenum allowing greater flexibility in the location of return air grilles. The suspended ceiling must be of noncombustible construction, with a flame-spread ratio of 25 or less.

D. Lighting Pattern

The lighting pattern for the computer area, normally contained within the suspended ceiling, should provide an overall maintained intensity of 40 to 80 foot-candles at a level of 30 inches above the floor. Light intensity greater than 80 foot-candle is feasible if either light dimmer controls or sectionalized switching is provided to allow the lighting level to be reduced.

E. Working Storage Area

It is recommended that a room be provided immediately adjacent to the computer area for storage of the necessary record media. The physical size of this room should be in keeping with the scope of the computer operation and the estimated use of these items. The climatic conditions of the area should be the same as those in the computer room. Construction of this area should conform to the requirements of NFPA Standard 76.

F. Bulk Storage Area

If large supplies of tape, cards, and printing forms are maintained, a bulk storage area may be desirable. This area may be remote from the computer area and need not conform to the temperature and humidity requirements of the computer area. The manufacturers recommend an environment of 40° to 120°F and 50% relative humidity for prolonged storage of tapes with a Mylar base. Prolonged storage of various recording media under adverse conditions may cause their deterioration. In transfer of materials from the bulk storage area to the working storage area, a minimum period of 48 hours should be provided for stabilization before use.

G. Fire Protection

(1) NFPA Standard 75

It is recommended that all governing codes be complied with in providing fire protection for the computer system and its associated areas. In particular, it is recommended that NFPA Standard 75 (Standard for the Protection of Electronic Computer Systems) be utilized in all site preparation planning.

(2) Fire Extinguishers

The following should be provided within the computer room and not more than 50 feet from the equipment: either a CO_2 hand hose system (which shall be commensurate with the size of the system to be installed), a minimum of four 15-pound capacity extinguishers, or a single portable unit with equivalent capacity. A minimum of one 10-pound capacity extinguisher should be provided in both the maintenance and storage areas. These extinguishers should be installed before equipment delivery.

(3) Smoke Detectors

A fire detection system based on combustion by-product detection is recommended. These detectors should be located in the computer room ceiling plenum and under the raised floor. The system should provide an audible alarm, but should not disconnect computer power.

(4) Sprinkler System

If it is necessary to install, or retain the use of, existing water sprinkler systems, it is required that sprinkler heads with a minimum of $212^{\circ}F$ tripping temperature be installed. In addition, an automatic power disconnect control (pressure-drop type or equivalent), which will function to shut off all power to the computer room upon discharge of the sprinkler system, should be installed.

(5) Manual Emergency Shut-off

A means of manually disconnecting primary power to the computer and to the air conditioning system in the event of an emergency should be provided. This switch (or switches) should be clearly labeled as to its purpose and should be shielded to prevent accidental activation. The suggested location is near the main exit. If separate switches are utilized for power and air conditioning, the location should be common for both.

H. Facilities Monitor Station

It is recommended that a facilities monitoring panel be located in the computer area to alert the operating personnel and maintenance engineers of failure or abnormal conditions in the facilities controlling the computer operation. Indication should be both visual and audible, with a means of manually disconnecting the audible alarm. Visual indicators should, wherever possible, consist of colored lamps indicating faults.

I. Power Requirements

(1) Input Power Specifications (60-Hz Power)

The basic 60-Hz power input for the computer system shall conform to the following requirements:

- Voltage: 120/208 volts nominal
- Voltage variation: +5%-10% from nominal
- Frequency: 60-Hz ±0.5-Hz
- Phase: 3 phase wye
- Connection: 5 wire (4 wire and ground)
- Harmonic distortion: 3% maximum.

(2) Electrical Service

A separate power transformer should be provided for the computer system. When this is not possible, the power sources used must be void of any heavy variable load such as elevator motors, air conditioning motors, etc. Tabulating equipment should not be connected to the same source as the computer system. It is recommended that all primary and secondary wiring be of UL-approved wire.

(3) Emergency Off

An emergency disconnect for the primary power to the computer should be provided. The switch should be labeled "Power Emergency Off" and should be shielded to prevent accidental tripping. The suggested location for this switch is near the main exit. This location should be common to both the power and air conditioning emergency disconnects.

(4) Power Termination

The computer manufacturer will provide a flexible power cord for termination at the power plug. The proper plug is to be provided within five feet of the power

entrance opening. If local code restrictions will not allow use of flexible cord connection, termination by means of conduit or other suitable means is permissible provided the system ground is not paralleled.

(5) Grounding

The grounding techniques used on the computer system are intended to complement, rather than supplant, the requirements for equipment grounding specified by the National Electrical Code and local codes. In addition to providing safety protection by reducing the possibility of shock hazard, the grounding network must provide a common zero voltage reference level between cabinets of the system and a means of dissipating all unwanted signals (noise), both those generated by the computer system and those generated from outside sources such as radio and radar transmitters and other computer equipment.

When designing the ground system it will be necessary to check the grounding requirements for each unit in the Installation Planning Guide.

(6) Grounding Method

A system ground bus is to be provided by the user. This bus is to consist of an insulated wire run under the false floor with the individual taps made to each unit. The main bus run must be equal in size to the incoming system main power line neutral, or I/O, whichever is larger. Individual taps are to be the same size as the input power lines to the unit, or Number 4 AWG, which is larger. This point must be common to the incoming power line neutral.

a. Flexible Cord Termination. In this method, the ground bus is connected at the designated frame ground location.

b. Conduit Termination. When a rigid conduit is required for distribution of power, the final short run of flex conduit terminated to the frame by means of an insulated bushing must not provide a ground path. Ground is provided by terminating the ground bus to the designated location on the frame.

(7) Convenience Outlets

120-volt, 60-Hz, single-phase service is required for the computer test equipment. Outlets for this equipment must be provided around the perimeter of the room at 8 to 12-foot intervals. The height should not exceed 42 inches above the floor.

(8) Responsibility

The user will be responsible for supplying and installing all AC power distribution including wire, conduit and circuit-breaker power termination devices. The user is also responsible for compliance with all applicable electrical codes.

K. Cooling Requirements

Continuous, reliable operation of the computer system is dependent on an efficient, well-designed and properly controlled air-conditioning system. Major heat producing units are cooled by internal fans, which circulate air through the cabinet. The cool air required for all units can be supplied by either a room supply or a raised-floor supply. Air is exhausted to the room from the top of the cabinet. Listed below are the basic requirements that must be considered regardless of the method used in cooling any of the components.

(1) Filtration

All air supplied to the computer system and to the computer area must be filtered in accordance with the requirements outlined below.

(2) Mechanical Filters

Mechanical filters are to have a minimum efficiency rating of 20%, per the Bureau of Standards Discoloration Tests using atmospheric dust.

(3) Electrostatic Filters

Electrostatic filters are to have a minimum efficiency rating of 85% per the Bureau of Standards Discoloration Tests using atmospheric dust. Since the efficiency of an electrostatic filter decreases with an increase in air velocity. It will be necessary to rate the filter using the maximum face velocity which may be expected in the system. The unit should be followed by a coarse dry filter.

(4) Pre-Filters

In many cases, it will be desirable to install mechanical pre-filters ahead of the high-efficiency filters to increase the time-between-service or decrease the replacement frequency of the high-efficiency units.

(5) Special Requirements

If salt air, corrosive gases, or air pollution are present, the air conditioning consultant should recommend the use of necessary special filters for removing or reducing the level to a degree which will not be detrimental to machine operation.

(6) Fire Protection

All filters should be of a type which will not burn freely or emit large volumes of smoke.

(7) Emergency Off

An emergency disconnect switch for the air conditioning system should be provided. The switch should be clearly labeled and shielded to prevent accidental tripping. The switch should control the operation of the fan motors and cutoff dampers.

(8) Operating Requirements

During all periods of operation, the room environment is to be maintained within the limits listed below.

- Temperature Requirements

  Minimum $50^{\circ}F$

  Maximum $90^{\circ}F$

  Recommended $72^{\circ}F \pm 3^{\circ}F$

  Gradient $10^{\circ}F$ per hour

- Humidity Requirements

  Minimum 40%

  Maximum 70% (not to exceed a dew point temperature at $61^{\circ}F$)

  Recommended 50% ±5

4.3.3 UTCS/BPS CENTRAL SITE INSTALLATION

The UTCS/BPS central site was designed in accordance with the guidelines enumerated in preceding paragraphs 4.3.1 and 4.3.2. A floor plan of the UTCS/BPS Washington, D. C., Control Center is given in Figure 4-7. The figure shows the relative position of the various system components. A layout drawing showing dimensions and contruction details is included in the Equipment Installation and Central Site Specification, UTCS/BPS Program, Appendix D.

A. Two-Stage Installation

A replica of the Washington, D. C. UTCS/BPS central site was initially installed at the Sperry Great Neck facility in early 1971. The system components, including interconnecting cables, were moved and installed in the site prepared in Washington, D. C., after a period of debugging, testing and operation, on May 1, 1972. The layout in Washington, D.C. is, with minor changes, the same as that at the Great Neck site.

The primary purpose of the Great Neck installation was to prove out UTCS and BPS control strategies and algorithms in conjunction with simulated traffic. Additional benefits were achieved, such as proving out the operability, maintainability, and the interconnection of the equipment complex. The two-stage process proved of value during the Washington installation. The interconnection and the powering of the equipments was accomplished quickly with only very minor adjustments.

SECTION 5

BUS PRIORITY SYSTEM INSTALLATION

5.1 INTRODUCTION

The Bus Priority System (BPS) evolved as an expansion of the Urban Traffic Control System (UTCS) Program. The objectives of the BPS Program were:

- To develop methods of giving buses preferential treatment through the use of traffic signal control
- To design and specify a system which could be used to test the usefulness of these methods in the UTCS area.

Studies and surveys were conducted which resulted in a system design and specification. A major task of the program was the development of the plan for the integration of the BPS into the already planned UTCS system.

Studies and surveys indicated, early in the program, that no suitable off-the-shelf detection equipment was available which could meet BPS requirements. This led to the development of a Bus Detection System required for the implementation of the BPS system.

This section describes the studies, tradeoffs, and control strategies which resulted in the BPS design configuration.

5.2 BUS DETECTOR REQUIREMENTS

The functional requirements as set forth in the Bus Priority Study (Reference 5A) include the following:

- The detectors must be able to distinguish buses from other types of vehicles and must be able to distinguish between buses that have a scheduled stop at the approaching intersection from through buses.

- Detection coverage must extend across all traffic lanes in the proper direction of bus travel but must not extend into the opposite direction traffic lanes. Also, the coverage range in the direction of travel must be less than the length of a bus to minimize the probability of being unable to separate buses entering or leaving a bus zone side-by-side or nose to tail.

- The detector sensing element must be mounted either in the roadway pavement or at the side of the road. Specifically, overhead mounts requiring mast arms, etc., are prohibited.

- The detector must be capable of detecting buses at speeds of 1 to 40 mph.

An additional requirement, that of making provision for a keying type of modulation, was also imposed. This requirement, while not necessary for the BPS tests, was added to permit future growth of the system to allow the transmittal of individual bus identification, loading, or other similar information. The production hardware and installation cost were comparable to corresponding costs of a standard vehicle detector.

High equipment reliability is required both to minimize the costs of maintenance and operation and in order to avoid jeopardizing the conduct and results of the BPS and UTCS testing.

5.2.1 BUS DETECTOR TECHNIQUES

Cooperative and non-cooperative detector techniques were considered during the Bus Priority Study. The requirement for distinguishing a bus which will stop at an intersection from one which will not immediately implied the use of a cooperative detection scheme; that is, the bus itself must indicate its intentions and must carry some means of doing so.

A number of possible techniques for cooperative detection were considered, techniques developed for the "Public Urban Locator System" (PULSE) among them.

These included radio trilateration and "signpost" techniques. All proved unsatisfactory, however, because they would not meet the location accuracy requirements of BPS. The location accuracy requirement of BPS also eliminated the high intensity beacon technique developed for emergency vehicle signal preemption systems.

5.2.2 CANDIDATE DETECTION TECHNIQUES

Two bus transmitter-type detector techniques were selected for extensive feasibility testing. One makes use of a UHF communications link and the other a near-field radio communications link. The UHF link was tested using an experimental model transmitter and receiver built for Sperry under subcontract. The near-field radio link was evaluated using laboratory equipment.

The UHF link tested operates at a frequency of approximately 400 MHz. This frequency band is commonly used for radio range telemetry and as a result components and design know-how are readily available. The attractive features of this equipment are the small size of the transmitting and receiving components, and a wide signal bandwidth (both due to the high carrier frequency), the ability to change the shape of the coverage pattern easily, and the low power required (under 100 milliwatts) which avoids FCC licensing problems. The UHF feasibility tests consisted primarily of coverage pattern measurements with simulated antenna installations and under simulated environmental conditions. The results showed that a satisfactory repeatable-coverage pattern could be achieved as long as the material surrounding the buried receiving antenna was dry and non-conducting. When the asphalt surrounding the antenna was damp or the pavement was covered with a conducting film of salt water, the coverage range was reduced to zero. Since it is felt that this represents a realistic street environment, the UHF technique was eliminated from consideration.

5.2.3 SELECTED BUS DETECTOR

The feasibility tests of the near-field radio technique showed it to be satisfactory in all respects, under all environmental conditions. In addition, it has been judged to have low development risk, which is significant because the detector is the only component of the BPS that is not an off-the-shelf piece of equipment. For these reasons this technique was selected for the BPS experiment.

For this application of the near-field radio link operates at frequencies between 160 and 190 kHz and makes use of long, narrow, vertically oriented loop antennas. The transmitting antenna (on the bus) is approximately one inch high and one foot long. The receiving antenna is one inch high and will be long enough to cross all the traffic lanes in a link that are used by buses. Loops up to 36 feet long have been successfully tested. The receiving loops are installed vertically in a saw cut in the pavement. At this frequency of operation, the dimensions of the antennas are small compared to the wavelength, so that the coupling

between the loops makes use of the near field of the radiation pattern and is equivalent to transformer coupling. The far-field propagation is extremely limited for the same reason. At the transmitter power levels being considered, FCC licensing is not required. Interference from other radio equipment will not be a problem since this frequency band is largely unused.

The vertical orientation of the transmitting and receiving loops has two important advantages. First, the installation of the receiving loop is simplified since only a single long saw cut must be made. More important, however, it results in an almost ideal coverage pattern for this application. Field tests (Reference 5A) have indicated that the pattern is narrow in the direction of travel (1 foot wide), extends the length of the receiving loop, and drops off sharply beyond the end of the loop. The result is that two buses passing almost side by side can be distinguished, and the possibility of detecting wrong-side buses is almost eliminated.

Because the detector was the only component in the BPS that required a development program, it was decided to design, build and test prototype models of the transmitter and receiver in order to reduce the risks involved in that development. The data obtained from the experimental models were used in writing the bus detector specification. The design and construction of the prototype models are described in Reference 5B. The bus transmitter is designed to transmit either of two frequencies in the 160 to 190 kHz band. The frequency is controlled by a switch which the bus driver will operate to indicate his intention to stop or go through the intersection. The receiver is tuned to receive both frequencies and produce either of two outputs depending on which frequency is received. The prototype model test results are described in detail in Reference 5B. The results confirmed the earlier results of the feasibility tests.

5.2.4 BPS DETECTOR PRODUCTION UNITS

BPS detector production units were manufactured in accordance with specifications per Reference 5B for Sperry under subcontract. Figures 5-1 through 5-4 are photographs of the transmitter and receiver components of the detector.

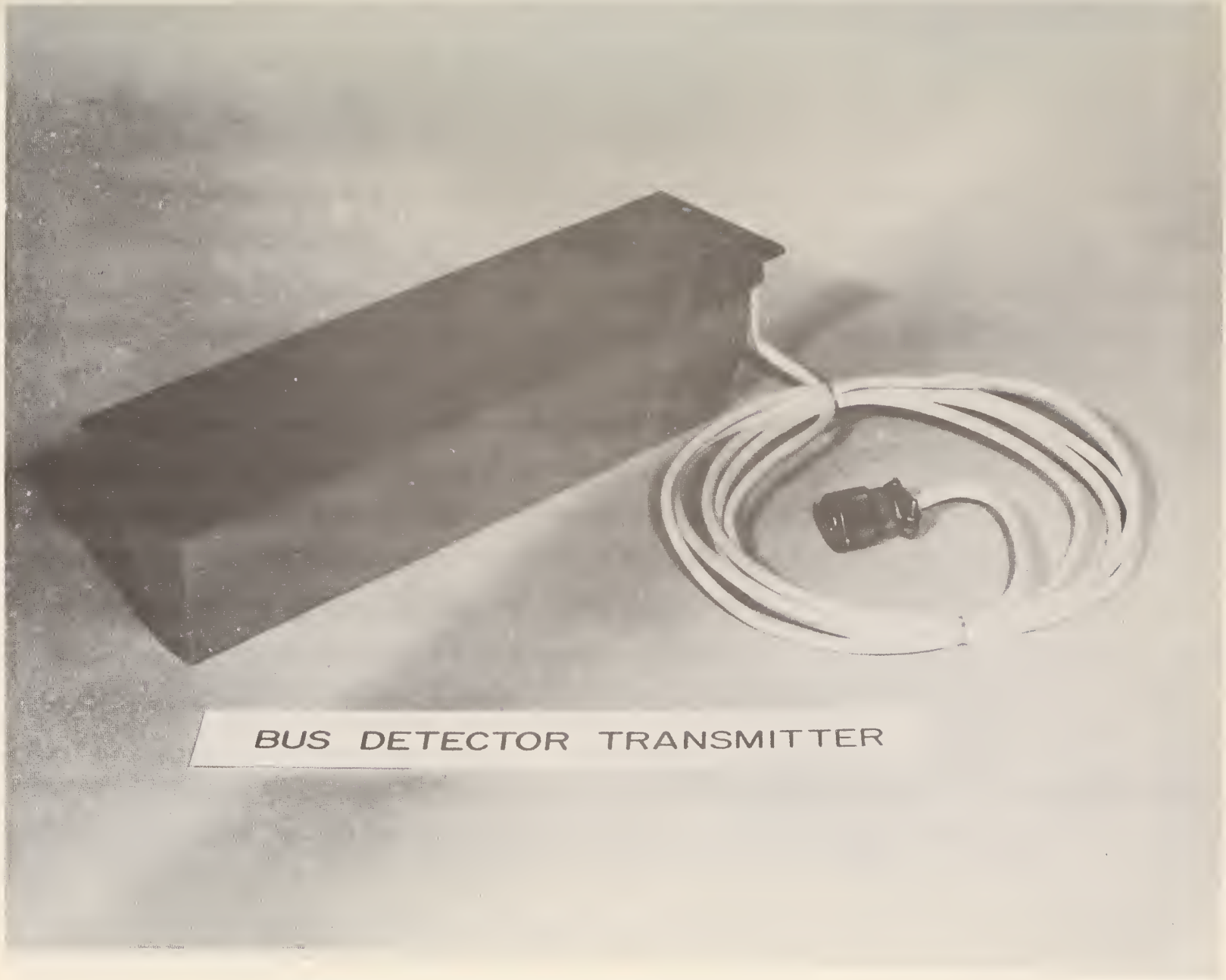


Figure 5-1. Bus Detector Transmitter (Top View)

R

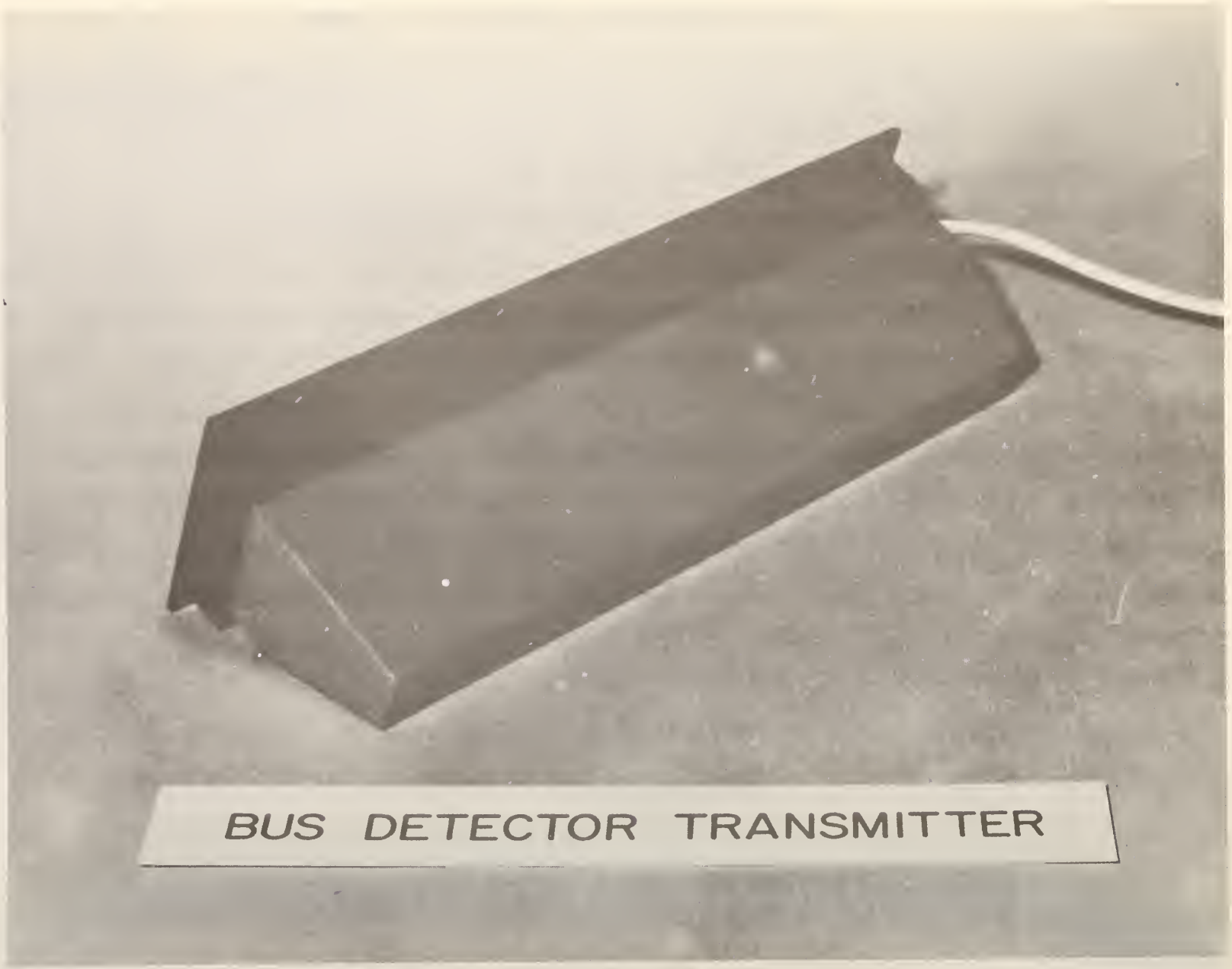


Figure 5-2. Bus Detector Transmitter (Bottom View)

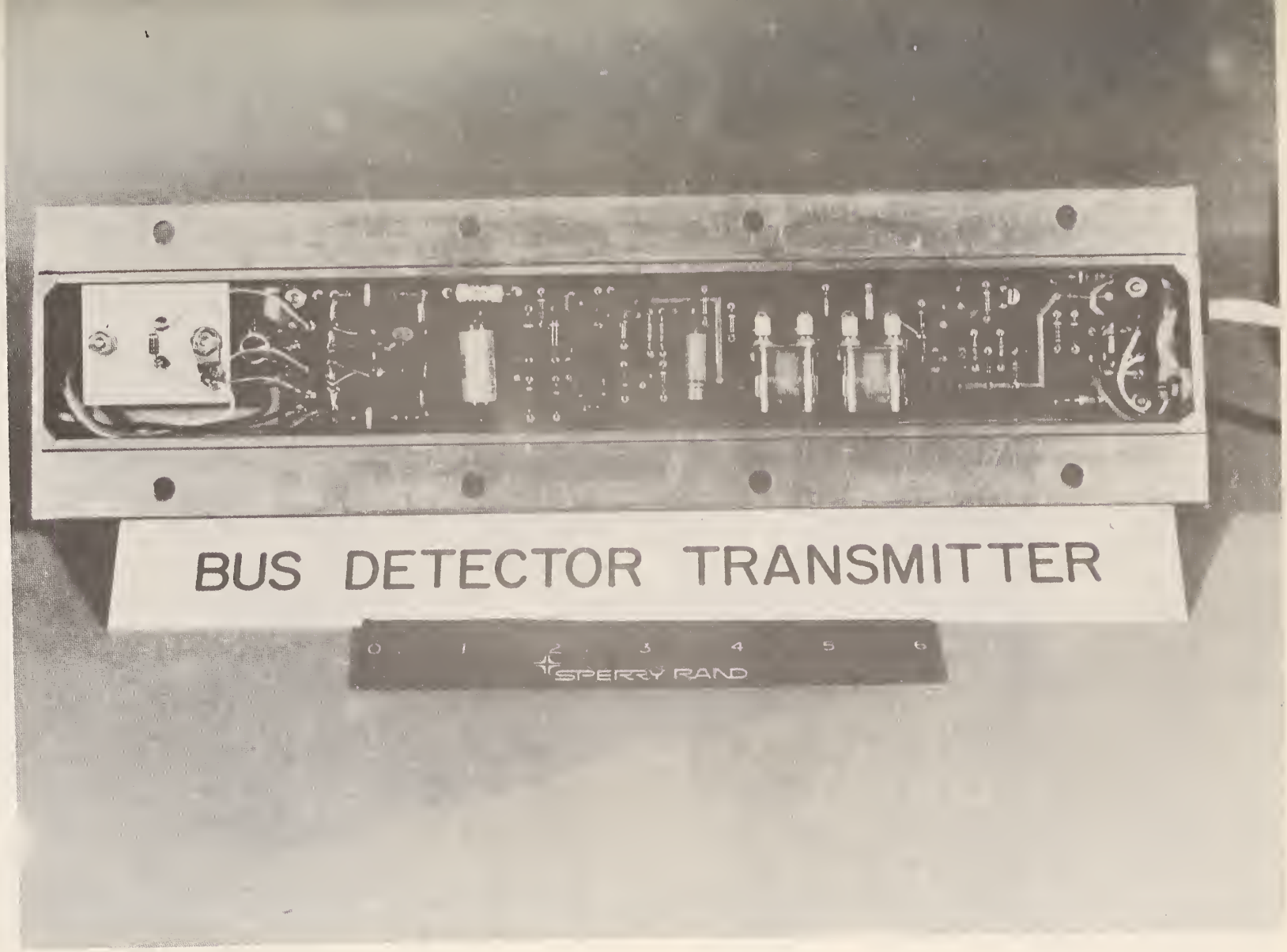


Figure 5-3. Bus Detector Transmitter (Top View, Prior to Encapsulation)

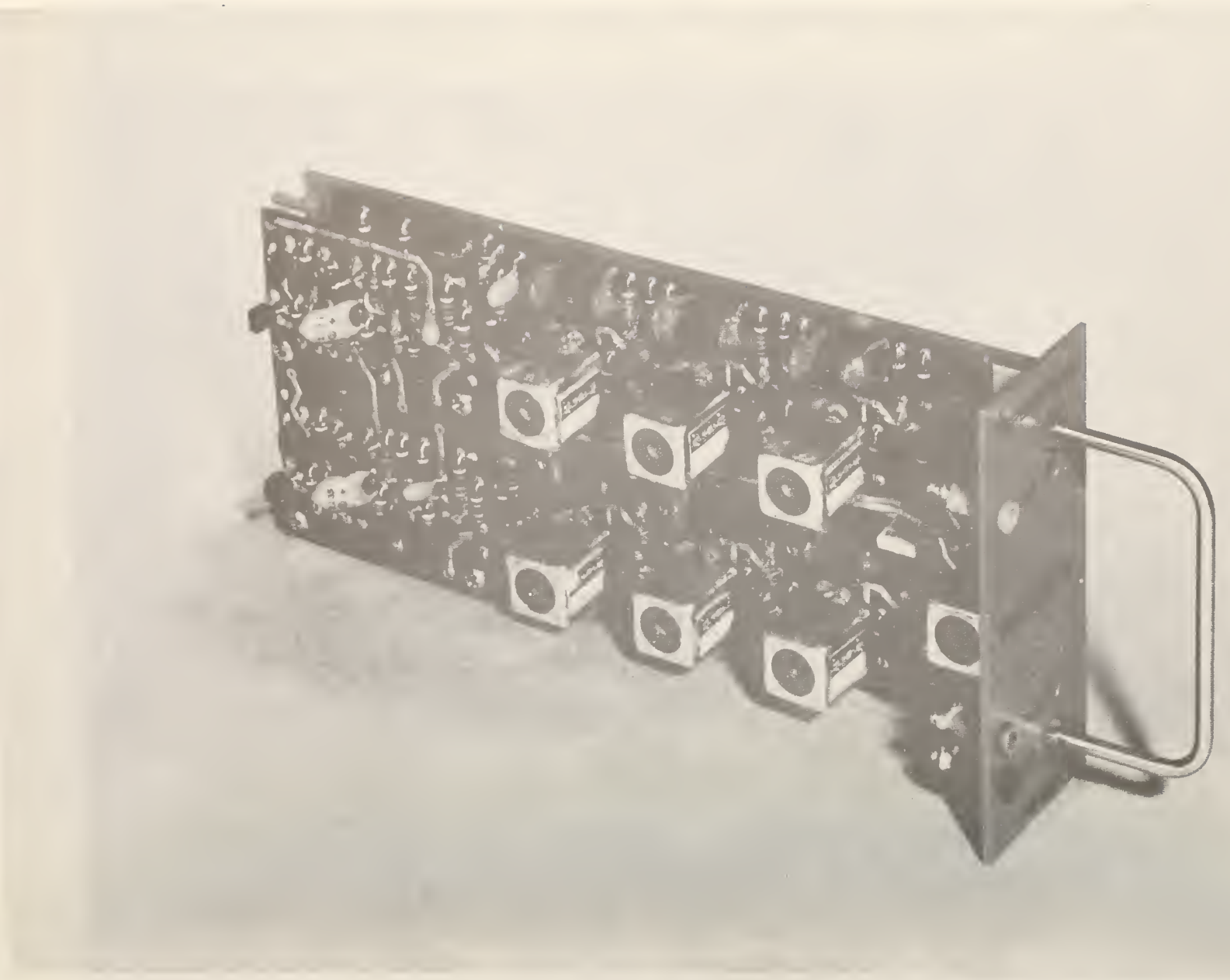


Figure 5-4. Receiver Module (Side View)

5.3 BPS DETECTOR CONFIGURATION AND LOCATION

Two detectors are used in the BPS to instrument a bus zone. One detector is located in the vicinity of the stop bar and the other about 200 feet upstream of the intersection.

BPS detectors are dispersed among the UTCS loop detectors. Figure 5-5 illustrates the position of bus detectors (B1 and B2) relative to queue detectors (Q1, Q2 and Q3) and volume detector (V1) of a typical UTCS intersection. BPS detectors extend across the lanes and are located relative to the stop bar. The UTCS/BPS street installation details centered at Constitution Avenue and 17 Street are illustrated elsewhere in this document. Actual locations of bus and vehicle detectors are indicated.

A single presence detector system, with the detector located within the area of the bus stop, was considered but was rejected because of serious disadvantages. The following paragraphs describe the rationale which led to the final selection of the dual detector system and the bus algorithm for granting bus extensions.

5.3.1 TIME OF ARRIVAL

In order to implement a bus extension properly, the time of arrival of the bus at the detector, with respect to the controller cycle, must be known. Since the priority will consist of a green extension, buses which are detected after the end of the green phase cannot be helped. On the other hand, not all buses which arrive in the green interval should receive priorities. Only those buses which have a good chance of making use of an extension should get one because delaying cross-street traffic unnecessarily is undesirable. There is, therefore, a band of arrival times within the green interval for which priorities can be granted. The length and the location of the "priority interval" is determined by the location of the bus at the moment it is detected (or equivalently the location of the detector), and the information about the bus that is obtained at that moment. For example, it is demonstrated below that if it can be determined some time before a bus reaches an intersection whether or not the bus is going to stop to load or unload passengers at the intersection (bus "status"), then the priority interval can be lengthened, thereby increasing the number of buses that can be helped.

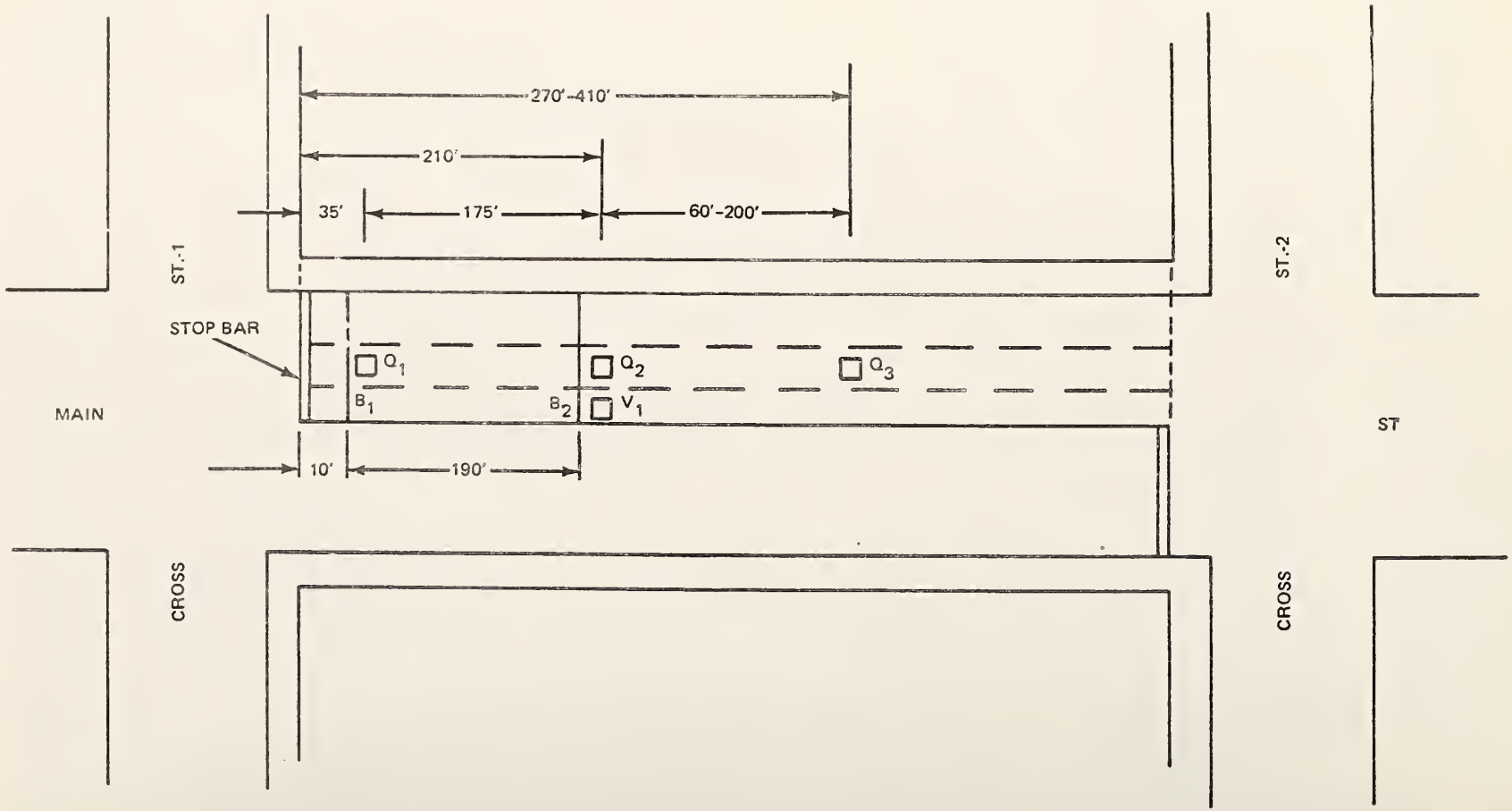


Figure 5-5. UTCS/BPS Detector Placement

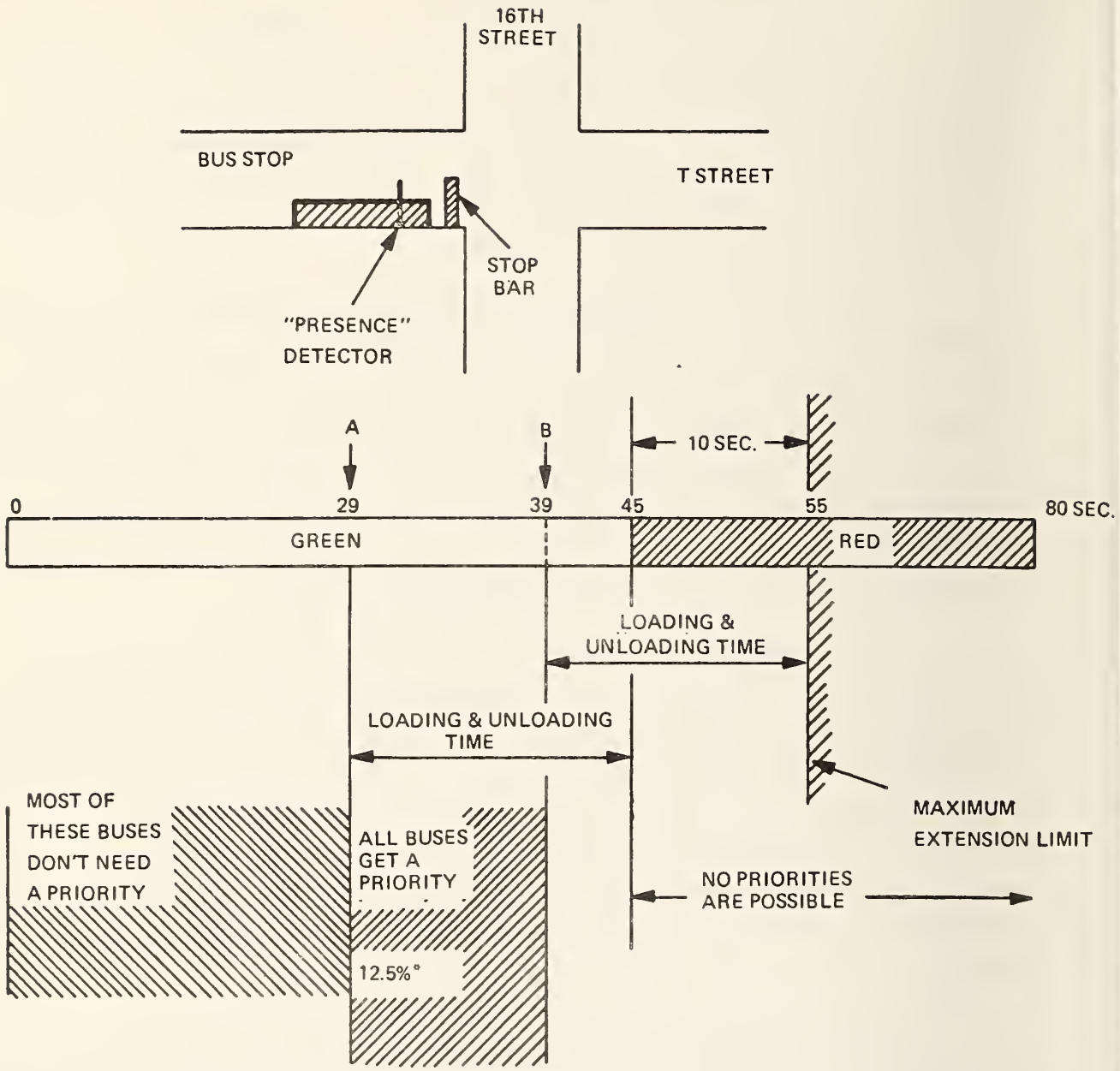
The manner in which the detector configuration and the decision to include bus status information in the algorithm were arrived at is described below. The procedure used is to postulate the simplest possible local control strategy, point out its deficiencies, and show what features should be added to correct them. In the following discussion it is assumed that the bus detector has a limited range and that a bus can be detected and transmit status information only when it passes over the detector location.

5.3.2 SINGLE DETECTOR SYSTEM EXAMPLE

Figure 5-6 is a timing diagram of a simplified controller cycle (red and green intervals only), which shows how the system would operate with a single bus presence detector located such that a bus is detected just before it stops at the bus stop. As shown in Figure 5-6 there is a maximum limit for the extension of the green phase. For A-phase extensions the limit is determined by the minimum cross-street green that must be allowed for vehicle and/or pedestrian crossing. In most cases the pedestrian crossing time will be the limiting factor. For B-phase extensions other factors must be considered, such as the necessity for maintaining an "A" street progression.

For each bus stop, there is also an average loading and unloading time required for buses that have to stop. This average time interval will change with time of day but can be determined from statistical data. Using this interval, the range of arrival times at the detector for which an extension can be made can be determined. The first bus that needs help arrives at the bus stop at time "A" in Figure 5-6. If this bus loads and unloads in the average time required for this bus stop, it will just get caught by the red signal. An extension of the green will permit this bus to make the light. Buses that arrive earlier than A should not be given an extension, since over half the time it would be unnecessary.

The last bus that can be helped arrives at time "B". A bus that arrives after B and loads and unloads in the average time will not clear the intersection even if it receives the maximum green extension. Even though this bus may arrive before the end of the green phase (depending on the length of the loading interval compared to the maximum extension interval), it should not be given an extension because over half the time the extension would be wasted. It should be noted that for this one-detector system, the decision to extend the green is made as soon as a bus is detected within interval A - B.



*PERCENTAGE OF BUSES THAT RECEIVE A PRIORITY ASSUMING A UNIFORM ARRIVAL DISTRIBUTION, AN AVERAGE LOADING AND UNLOADING TIME OF 17 SECONDS, AND A MAXIMUM EXTENSION OF 10 SECONDS.

Figure 5-6. "Presence" System Timing Diagram
(Single Presence Detector Example)

Figure 5-6 includes a numerical example which illustrates the situation described above, using cycle times from the intersection of T and 16th Streets and bus loading time data collected on 16th Street between I and U Streets. For this example the interval during which buses can be given priorities is 10 seconds long. As long as the loading time is greater than the maximum extension, the priority interval is equal in length to the maximum extension interval. If it is assumed that buses are equally likely to arrive at any time during the controller cycle, then at most 12-1/2 percent of the buses will get a priority (provided the traffic conditions around the intersection permit it).

The simplified system described above, with a bus presence detector located at the bus stop, has three serious shortcomings:

- Through buses which arrive during the priority interval will get a priority even though they don't need it because the system must assume that all buses have to stop. In this case, cross-street traffic is held up unnecessarily. Data collected at 20 intersections in the test area showed that at least half of the buses approaching an intersection do not stop to load or unload. So while 12-1/2 percent of all buses would get priorities, only 6-1/4 percent would actually need them.

- Through buses which arrive at the detector just after the end of the green interval cannot be given an extension even though they could be helped without exceeding the maximum extension limit. This virtually eliminates the possibility of helping a through bus that actually needs help.

- Stopping buses which arrive prior to point A and which require longer than the average time to load are not eligible for an extension even though they could use help.

5.3.3 DUAL STATUS DETECTOR SYSTEM

The first of the shortcomings listed above can be eliminated by extending the capability of the bus detector to enable it to distinguish between a through bus and a stopping bus (status information). This would prevent priorities from being wasted, but would still not permit through buses which arrive after the signal turns red to be helped because this is an irreversible event. If, however, the use of status information is coupled with

the addition of a bus detector upstream so that buses are detected some time before they reach the intersection, then the first two problems can be solved and a significant improvement in performance results.

The third problem can be solved by also making the downstream detector a status detector, and moving it toward the stop bar so that a bus cannot cross it until it is committed to entering the intersection.

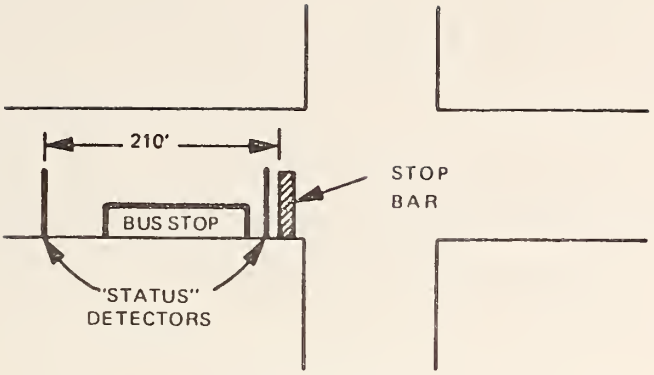
With this dual detector configuration, the system can keep track of the through and stopping buses in a bus zone between the two detectors, and determine which of them are eligible for a priority. The decision to extend or not to extend is made just before the normal end of the green interval. If all the eligible buses leave the bus zone before the normal end of the green interval then no extension is made.

Figure 5-7 is a timing diagram similar to Figure 5-6, which shows how the time-of-arrival criterion for determining the eligible buses was developed for the dual status detector system.

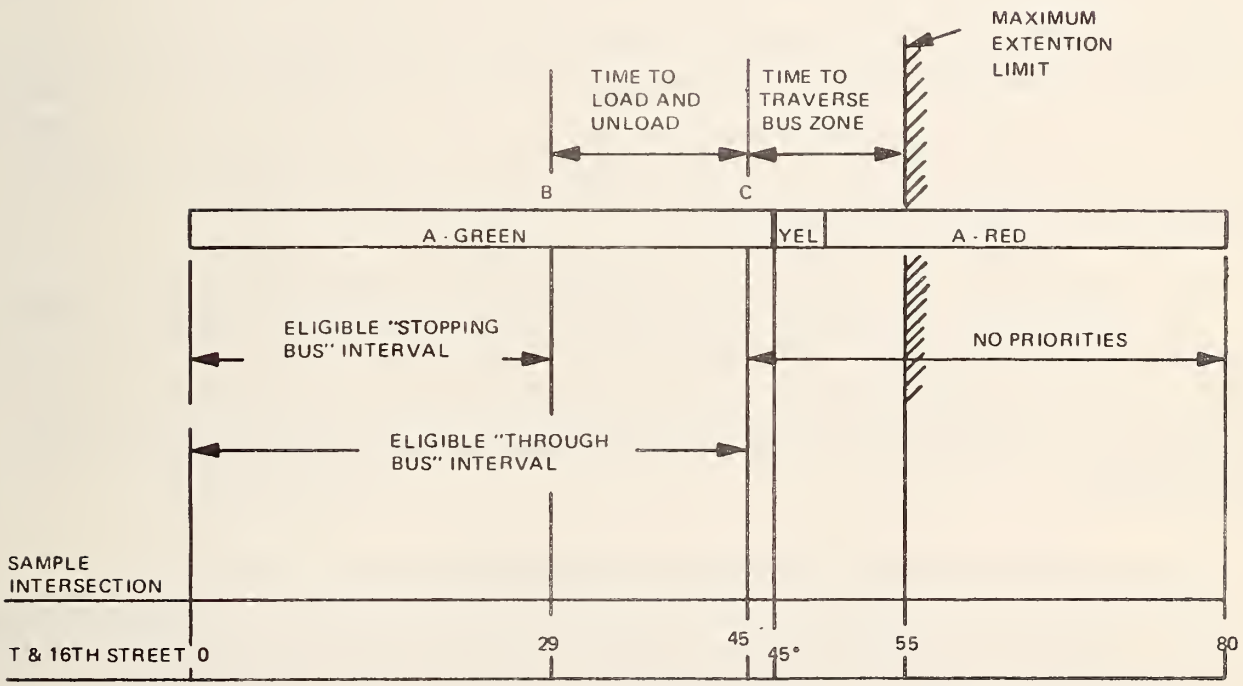
The interval over which a stopping bus is considered eligible for an extension is now much longer than in the previous example. (It could extend back into the previous cycle but for practical reasons it has been limited to the start of the green interval.) Most of the stopping buses which arrive at the upstream detector very early in the green interval will not need an extension; however, they will all be considered eligible as long as they are in the bus zone. The early arriving, slow loading bus that could not be considered eligible with a single detector system can now be helped.

For a through bus the boundary is at point C in Figure 5-7. A through bus that arrives after time C cannot be given a priority even though the signal may not have turned red, because it will arrive at the intersection after the maximum extension limit, and have to stop anyway, in which case the extension would be wasted. The eligible through bus interval also extends back to the start of the cycle which permits through buses that are slowed down by traffic congestion in the bus zone to be helped.

The advantages of the dual status detector system can be summarized as follows:



BUS DETECTOR LAYOUT



*IN THE EXAMPLE, THE TRAVERSAL TIME IS EQUAL TO THE EXTENSION INTERVAL. AS A RESULT POINT C SHOULD OCCUR AT THE END OF NORMAL GREEN. HOWEVER, TO ILLUSTRATE THE GENERAL CASE, WE'VE SHOWN THEM SEPARATED.

BUS ZONE = 210 FT.
TRAVERSE TIME = 10 SEC.

AVG. SPEED = 20 FT./SEC.
AVG. LOAD TIME = 16 SEC.

Figure 5-7. Status System Timing Diagram (Dual Detector Example)

- The addition of status information in the BPS algorithm prevents priorities from being given to through buses which do not need them, and, when combined with an upstream detector location, permits additional priorities to be given to through buses which do not need them.

- The downstream detector located at the stop bar permits more buses to be considered eligible for priorities because it permits the system to postpone its decision to extend the green until the last second, and base its decision on the actual occupancy of the zone at that time.

5.3.4 UPSTREAM DETECTOR LOCATION

The best location for the upstream bus detector is determined by the length of the maximum green extension and the average speed of a bus as it approaches the intersection. The detector should be located so that the time to traverse the bus zone is equal to the maximum green extension. This will cause the time C in Figure 5-7 to occur at the normal end of the green interval. If the detector is moved closer to the intersection, the traverse time becomes less than the extension limit and some helpable through buses will not reach the detector before the end of the green interval. Moving the detector further upstream does not produce any improvement.

The maximum green extension at most intersections will be 10 seconds. Using an average link speed of 21 feet per second (this is the value used in UTCS software routines for the computation of stops), this criterion calls for a detector location approximately 210 feet from the intersection, which places it approximately at the location of one of the UTCS queue detectors.

5.3.5 SUMMARY OF TIME-OF-ARRIVAL CONDITIONS

The time-of-arrival conditions are the most important part of the BPS algorithm. The conditions for through and stopping buses may be summarized as follows (see Figure 5-7).

- A stopping bus is eligible for a priority if it arrives at the upstream detector during the green interval prior to a time determined by subtracting the sum of the traverse time and the average loading time for the link from the cycle time representing the maximum allowable extension of the green interval.

- A through bus is eligible for a priority if it arrives at the upstream detector during the green interval prior to a time determined by subtracting the traverse time from the cycle time representing the maximum allowable extension of the green interval.

- An extension of the green interval will be made if there is an eligible bus remaining in the bus zone at the end of the normal green interval, and the other conditions of the algorithm are satisfied.

5.4 SELECTION OF THE CONTROL STRATEGY

The first task in the system design was to identify and evaluate applicable control strategies and decide which should be implemented in the experimental BPS system.

Ideally, the system should be designed to permit the evaluation of all possible techniques, but realistically, only the most promising and the most flexible can be implemented.

The control strategies evaluated fall into two general categories:

- Area-wide signal control techniques in which signal patterns that favor bus travel are developed from an area-wide consideration of traffic conditions.

- Local control techniques in which the signal timing at individual intersections is adjusted to favor individual buses as a result of conditions at or very near the intersection.

An important distinction between the two techniques lies in the time scale in which they operate. Area control may be thought of as a long-period or steady-state strategy. Although the area-wide signal pattern in effect may be changed many times during the day, it will be constant for a great number of controller cycles at a time. Local control strategies, on the other hand, operate on a cycle-to-cycle basis in response to the presence of individual buses.

5.4.1 AREA CONTROL

The operation of an area control strategy for helping buses can best be explained against the background of the UTCS area control technique. In simplest terms, the UTCS will store pre-computed signal patterns consisting of combinations of signal parameters (cycles, splits and offsets) for groups of intersections called sections. A number of patterns

will be available for each section corresponding to the whole spectrum of traffic conditions that can exist in that section. The signal patterns are computed off-line by a signal optimization technique like SIGOP (Traffic Signal Optimization Program, Reference 6A). A signal pattern for a section can be called up in three ways:

- Automatic time-of-day pattern selection
- Manual operator selection of pattern
- Automatic selection of pattern by traffic-responsive algorithm.

In the latter method, volume and occupancy data derived from detector data are averaged and periodically compared to sets of stored traffic data (histories), each of which corresponds to one of the stored signal patterns. The stored data that comes closest to the measured traffic conditions is identified, and the corresponding signal pattern is called up. The comparison between current data and stored histories is made every 15 minutes and a new signal pattern called up if necessary.

The first area-wide control strategy that was considered involves the use of a bus weighting factor. A weighting factor for a bus with respect to a car which is a function of its relative length, acceleration profile, and number of passengers can be derived. Using bus detector data (or even bus schedule data), the average volume of buses in all links is determined and the weighting factor is applied. When the weighted bus volume data are added to the vehicle data, the resulting volume data will then appropriately reflect volumes of people rather than vehicles. As a result of using weighted data, the UTCS algorithm will select a somewhat different signal pattern, one that presumably will favor bus routes.

There is a fundamental error in this approach. It lies in the assumption that all the vehicles represented by the weighted data will act in the same way. For example, it is implicitly assumed that the acceleration profiles, platoon dispersion rate, departure and arrival headways, etc., are for vehicles which all have the same objective. That is, it is assumed that all the vehicles want to continue through the network with a minimum of stops and delays. The assumption is wrong, of course, because buses have the additional constraint of having to stop to load and unload passengers. In other words, the equations of motion for bus passengers and car passengers differ.

The data shown in Table 5-1 illustrate this point. They show the effect of passenger loading on bus travel time. It can be seen from these data that the free running time

of buses (a rough indication of the bus equation of motion when the bus is behaving like a car), is quite predictable. When the loading time is included, however, the variance of the link-to-link running time increases considerably.

Returning to the problem of pattern selection, the use of weighted bus data in the UTCS algorithm will result in the selection of a pattern that is optimized for the actual cars present plus the "pseudo" cars represented by the bus. This pattern will have splits more favorable to bus routes, but in general it will not match the real traffic situation and may have an adverse effect on all traffic flow including buses.

To correct this fault, sets of traffic signal patterns which are optimized for a mixed population of buses and other vehicles, and which take into account the differing equations of motion of both, are needed. The comparison between current data and stored histories would then include both bus and car parameters. In order to generate these patterns, an optimization program such as SIGOP, but more complex, is required. In the SIGOP procedure, the signal splits are first determined for each intersection on the basis of volume data. In the next step, cycle lengths and offsets that minimize vehicle stops and delay are computed. The data required are the physical characteristics of each link, such as block length, grade, parking friction, desired free-flow speed, and turning probabilities. The equations of motion of vehicles, and the dispersion and headway characteristics of platoons of vehicles, are also required.

To generate patterns that favor buses, bus volume data can be used to compute splits based on passenger volumes, while the bus equations of motion influence the cycle and offset computations. The procedure appears to be feasible but there are certain problems involved which cast doubt on the usefulness of the result. For example, the efficiency of the offsets computed is directly related to how well the equations of motion can predict how a platoon will progress down the block. As given in Table 5-1, the predictability of bus progression through a network is severely degraded by the variations in passenger loading time. Furthermore, the loading periods naturally result in a reduction in the effective speed of a bus. The latter implies that the offsets computed to help buses would call for lower speeds and would slow down traffic in general.

The control strategy of lowering the speed of progression to produce less transit delay for buses was evaluated in an experiment conducted on 16th Street in Washington, D. C. in 1962. It was believed that timing the signals to match bus speeds would encourage other traffic to divert to 15th or 17th Streets which were made one-way at the same time.

TABLE 5-1

SUMMARY OF BUS TRAVEL TIME STATISTICS

	Free Running Time (sec.)		Passenger Loading Time (sec.)		Free Running and Load Time (sec.)	
Link	Mean	Std. Deviation (1σ)	Mean	Std. Deviation (1σ)	Mean	Std. Deviation (1σ)
U St. to T St.	26	6.1	17	9.9	43	11.6
T St. to Swann St.	10	5.1	-	-	10	5.1
Swann St. to S St.	10	3.6	-	-	10	3.6
S St. To Riggs Pl.	14	5.0	10	21.4	24	17.1
Riggs Pl. to R St.	12	3.6	-	-	12	3.6
R St. to Corcoran St.	15	5.1	8	9.5	23	12.0
Corcoran St. to Q St.	12	5.5	-	-	12	5.5
Q St. to Church St.	9	2.4	-	-	9	2.4
Church St. to P St.	17	3.6	15	7.0	32	8.7
P St. to O St.	13	3.1	-	-	13	3.1
O St. to M St.	27	5.2	-	-	27	5.2
M St. to L St.	32	6.8	11	6.0	43	10.2
L St. to K St.	31	6.9	18	7.4	49	10.2
TOTALS	228	27.0	79	26.0	307	35.6

Although the results of the tests were not conclusive, they indicated that very little improvement was obtained. Although the delay for buses caused by traffic and traffic signals decreased, the running time increased to offset the improvement.

Other problems associated with area control strategies arise from attempting to adjust splits on the basis of passenger volumes. Table 5-2 gives actual car and bus volume data from five intersections in the BPS test area.

TABLE 5-2. EFFECT OF USING WEIGHTED VOLUMES TO DETERMINE SIGNAL SPLIT

Intersection	Time	15 Minute Car Volume N-S/E-W	15 Minute Bus Volume N-S/E-W	Weighted Volumes N-S/E-W	Split Change In Percent of Cycle Length
H St. & 17 St.	8:14AM	508/549	8/8	628/669	+0.4
L St. & Conn Ave.	7:45AM	378/104	27/18	783/374	-10
L St. & 16 St.	7:25AM	259/182	24/1	619/197	+15
L St. & 16 St.	7:15AM	118/164	11/20	283/464	-4
L St. & 20 St.	8:34AM	334/281	23/0	679/281	+17

The last column in the table shows the change in split that would occur at these intersections if the basis for computing the split changed from actual volumes to weighted volumes. A weighting factor of 15 was used based on passenger occupancy of a bus versus two cars.

One problem that is immediately apparent is that at an intersection like H Street and 17 Street where there is balanced bus usage, no change would result and no buses would be helped. At other intersections like L Street and 20 Street, there would be a considerable change which would increase the probability that a bus could get through the intersection without stopping. For the 80-second cycle length commonly used in the test area, a 17-percent change represents an extension of the green interval for buses of 13.5 seconds. This brings up a problem which is inherent in any area control scheme: even where there are high bus volumes, only a fraction of the buses using an intersection would make use of the extra green time, yet the extra green time is available on every cycle. A considerable part of the time the cross-street traffic is therefore being penalized unnecessarily. This can be demonstrated roughly by making the assumption that bus arrivals at an intersection are uniformly distributed during the controller cycle. If the green time for the bus is increased by 17 percent, then, very roughly, 17 percent of all buses approaching that intersection will make use of that additional green time to get through the intersection without a signal delay. In other words, this fraction of all buses will arrive at such a time that they would get caught by the light if not for the extra green time provided. The corollary of this is that over a period of many cycles during which the additional green time is provided, 83 percent of the time it is not used. Depending on the main-street and cross-street volumes, there may be a net increase in passenger delay at the intersection.

On the basis of the preceding considerations, the following conclusions have been drawn:

- The implementation of an area control system requires the generation of new optimized signal patterns based on a mixed population of buses and other vehicles. The task is a considerable one and requires additional bus data not now available.

- In a grid environment with many crossing bus routes (such as the UTCS test area), the new signal patterns will not be able to give buses priorities except in the sense that offsets may be adjusted to match the slower speed of buses at the expense of traffic in general.

- At intersections where it is possible for the new signal pattern to give more green time to buses, most of the time the extension will be wasted, which may result in a net increase in passenger delay.

The overall conclusion is that the area control strategies are not appropriate because they represent a steady-state solution to what is essentially a transient problem. The result is that they do not appear to satisfy the performance objectives published for the BPS.

5.4.2 LOCAL CONTROL

In contrast to the area control technique described above, a local control strategy operates on a short-period basis. It also modifies the intersection controller cycle to favor buses, but does it on a cycle-to-cycle basis for individual intersections in response to the presence and status of individual buses approaching the intersection and the traffic conditions around the intersection. For this reason, local control has the potential for much higher performance - in terms of passenger-seconds of delay saved - than area control. For example, during cycles when no buses are present, no changes in controller intervals are made and the cross street traffic is not unnecessarily penalized. Furthermore, as described in succeeding paragraphs, the local control system will be designed to deny priorities to buses that do not require or are unable to use them. This results in additional performance improvement.

It is felt that this advantage is significant enough to outweigh the greater cost of implementing this technique. Local control will require the installation of bus detectors at each intersection that is to be part of the experiment. In addition, the amount of on-line

computation required will necessitate additional computing capacity to be added for the combined UTCS/BPS. Area control, on the other hand, could probably be implemented with fewer detectors and could make use of the excess capacity of the UTCS computer. As pointed out previously however, this approach has limited effectiveness. Moreover, its lack of flexibility and growth potential make this course of action too risky for use in an experimental, test-bed type of system. The implementation of the local control technique, although more costly, will leave the door open for later experimentation with other strategies, including area control. The alternative course of action would not have this advantage.

For these reasons, the local control strategy was chosen for implementation in the BPS.

5.4.3 DEVELOPMENT OF THE LOCAL CONTROL ALGORITHM

Within the operational constraints imposed on the BPS, there is only one practical way to modify the controller cycle to favor buses: to extend the green phase to allow a bus that would ordinarily be stopped to make the light. The additional green time is obtained by reducing the length of the cross-street green interval. The total cycle length is maintained. This is an efficient technique because a few seconds extension can save a bus almost the whole cross-street green interval, which could be as much as 30 or 40 seconds. This multiplying factor results in positive gain for this method; that is, the number of bus passenger-seconds saved exceeds the number of cross-street car passenger-seconds lost.

Another possible technique would be to advance the start of the green phase. However, it only reduces the bus delay on a one-for-one basis. The gain of this method is too low for it to be considered. The passenger-seconds lost by truncating the cross-street green interval may even exceed the bus passenger-seconds saved, resulting in a negative gain.

Once it was decided that the mechanism for granting priorities to buses would be the extension of the green interval, the next step in the system design was the design of the BPS algorithm. The algorithm is the set of rules or conditions that must be satisfied before a priority can be granted, and the subsequent procedures to be followed. These conditions are concerned with the following three aspects of the situation:

- The time of arrival of a bus, which determines if it needs and can make use of a priority

- The effeet that a green extension would have on traffie flow

- The gain or passenger-seeonds of saved, that would result from the extension.

5.5 MEASURES OF EFFECTIVENESS (MOE)

5.5.1 SELECTION OF MEASURES OF EFFECTIVENESS

A number of MOE's were eonsidered before making a final ehoice of those best suited to evaluate bus priority performanee. The MOE's considered fall into two groups: those MOE's measured by UTCS and those additional MOE's required for the bus experiments.

Each of the MOE's measured by UTCS (delay, stops, queue, volume, oeeupaney, travel time and link speed) was examined; it was eoneluded that all would be useful in evaluating bus experiments. (As mentioned earlier, changes have been made to the UTCS program to preserve the UTCS MOE structure when exercising BPS control.)

Five additional MOE's (hereafter referred to as BPS MOE's) were initially eonsidered for the BPS experiments. The candidate BPS MOE's were total signal delay, total trip time, passenger waiting time, intersection gain, and total stops. These have the following eharacteristics:

- Total signal delay: reflects directly the reduetion of bus signal delays by bus priority extensions

- Total trip time: although eertainly meaningful, this MOE is noisy and somewhat insensitive to bus priority performance due to the variability of other eomponents of trip time (e.g. loading time, running time, ete.)

- Passenger waiting time: a meaningful MOE but very diffieult and eostly to measure

- Interseetion gain: eompares the decrease in signal delay experieneed by passengers helped by bus priorities with the additional delay experieneed by passengers who are penalized by bus priorities. It is a direct measure of the effect of bus priorities and is measured automatieally by the bus priority control algorithm

- Total stops: reflects the reduction in unplanned stops by bus priority extensions.

The sensitivity of each of the MOE's and the ease with which each might be measured was studied. This study revealed that of the five, total signal delay, total stops, and intersection gain were the most suitable.

In summary, the measures of effectiveness selected for the bus priority program can be categorized as follows:

- Total signal delay and total stops provide a measure of system effectiveness over the individual bus routes in the area
- Intersection gain provides a measure of system performance localized to the individual intersections
- UTCS MOE's provide a measure of the effects that the bus priority experiments have upon general vehicular traffic.

The total reduction in signal delay and stops is derived from a simple comparison of the average signal delay before and after the BPS is enabled along the various bus routes. The intersection gain for two one-way streets with one bus being granted an extension is as follows:

> Intersection gain = (bus passenger gain) + (main street car passenger gain) - (cross-street car passenger loss due to extension and due to truncation from the platoon).

The preceding is a simplified version of the equation that is actually mechanized in the BPS software specification.

5.5.2 BPS ALGORITHM

The granting or denial of a green extension to favor bus traffic at an intersection is based on the continuous computation of intersection gain. The determination of the alteration of split is made one second prior to the start of amber on all links carrying bus traffic into a BPS intersection. (A special circumstance arises for preempt operation of a BPS intersection. Here, the simple presence of an eligible bus results in a favorable decision for a green extension without resorting to an actual measure of its value.) In normal operation the following conditions must be met to result in a decision favoring a green extension:

- The intersection has been enabled for BPS operation by the operator via the traffic control panel.
- The UTCS/BPS inhibit flag must not be set for the intersection (refer to 2.2.1 B(2) for conditions under which a bus intersection can be inhibited).
- One full cycle time must have elapsed since the previous extension at the intersection.
- Cross-street queues must not exceed a preset limit of nine vehicles.
- Eligible buses are present to take advantage of the green extension.
- The intersection gain associated with a green extension must exceed a preset threshold value (two passenger-minutes).

Following the granting of an extension and one second before its expiration, intersection gain calculations are repeated. The value computed on this second pass is a more accurate representation of the true worth of the extension because helped rather than eligible bus counts are used and because queue values are updated to those existing at the end of the extension interval. Finally, an apportionment of the intersection gain is made to those links benefiting from the extension on the basis of bus-helped counts per link.

The intersection gain is computed by summing gain (positive) and delay (negative) factors as follows:

- Car gain: passenger minutes saved due to favored car throughput during the extension period
- Bus gain: passenger minutes saved due to favored bus throughput during the extension period
- Queue delay: passenger minutes lost due to delay of queued cross-street traffic by the extension period
- Truncated car delay: passenger minutes lost due to the inability of some queued cross-street cars to clear the intersection because of the extension
- Truncated bus delay: as above, but for cross-street buses.

Each of the gain factors is computed for every "going red" link and each of the delay factors for every "going green" link at the intersection. The gain values are computed on two passes for the reasons indicated above. The following mathematical expressions are used:

$$CG = (FR - \frac{TEW}{2})(\frac{TEW}{2.1})(1.5\ LC)$$

$$BG = (FR - \frac{TEW}{2})\ (ESBC + ETBC)\ (BL)\ \text{(first pass)}$$

$$BG = (FR - \frac{TEW}{2})\ (HSBC + HTCB)\ (BL)\ \text{(second pass)}$$

where

$(FR - \frac{TEW}{2})$ = Average minutes saved; favored street red interval less half the extension period

$\frac{TEW}{2.1}$ = Car throughput per lane for extension period

1.5 LC = Scaling factor (1.5 passengers per car times the lane count)

(ESBC + ETBC) = Number of eligible stop and through buses

(HSBC + HTBC) = Number of helped stop and through buses

BL = Bus passenger load (varies with time of day)

The delay factors are then computed on the "going green" links. Here, computations are the same for the first and second passes. For each "going green" link the queue and queue delay are first calculated as follows:

$$Q = ZD0 + ZD1$$

$$QD = TEW\ [Q * 1.5\ LC + ZC\ (BL)]$$

where

Q = Queue on link

TD0 = Car count in Zone 0

TD1 = Car count in Zone 1

QD = Queue delay in passenger minutes

TEW = Extension interval

1.5 LC = Scaling factor

ZC = Bus count in bus zone

BL = Bus passenger load

Next, the number of cross-street cars prevented from clearing the intersection on the following cross-street green is computed. This is simply the difference between the number of cars clearing during normal cross-street green and those clearing during the shortened green following an extension on the favored street. Mathematically, this is given by:

$$TC = NGC - SGC$$

$$NGC = 5 + \frac{G - 14.2}{2.1} \text{ ; (or Q, if smaller)}$$

$$SGC = NGC - \frac{TEW}{2.1} \text{ ; (or Q, if smaller)}$$

where

TC = Cars truncated per lane

NGC = Cars clearing on normal green per lane

SGC = Cars clearing on shortened green per lane

G = Normal corss-street green interval

TEW = Extension interval

Q = Queue per lane

The smaller value of NGC or Q (and SGC or Q) is used as indicated above and on the logic flow diagram. Thus, when the queue is less than both NGC and SGC, no truncation will occur.

For each "going green" link the three delay factors are then computed based on the following expressions:

$$TCD = (XR - \frac{TEW}{2}) \quad [TC * 1.5 LC]$$

$$TTBD = \frac{TC}{Q} ZC * BL$$

$$TSBD = 2 TTBD$$

where:

TCD = Passenger minutes delay due to truncated cars on cross-street

(TTBD), (TSBD) = Passenger minutes delay due to truncate through (stop) buses on cross-street

$XR - \frac{TEW}{2}$ = Truncated car delay interval; cross-street red less half the extension period

TC = Truncated cars per lane

1.5 LC = Scaling factor

Q = Queue per lane

ZC = Bus count in zone

BL = Bus passenger load

Truncated bus counts are seen to be proportional to truncated car counts with stop buses considered twice as prone to truncation as through buses. These factors will probably change as real-time traffic control experience is gained.

After computations have been completed on all contributing links, a summation is made to obtain the overall intersection gain.

5.5.3 CALIBRATION OF THE BPS ALGORITHM

The following parameters affect the calibration of the BPS algorithm:

- Loading and unloading time, which varies with each intersection approach (link) and with the time of day
- Traversal time, or the time required to transere the 210-foot bus zone
- Bus passenger load, which also varies with the link and time of day.

The most sensitive parameter in the algorithm is the loading and unloading time, because of its powerful effect on the length of the priority interval and, consequently, on the number of buses eligible for a priority. The traversal time also affects the number of eligible buses, but to a lesser extent because of its lesser variability. The bus passenger load directly affects the computation of the intersection gain, from which the granting of a bus extension is determined.

The BPS program provides tables which store the loading and unloading time and the passenger load as function of the zone and the time of day. Preliminary values have been inserted into these tables based on analysis of traffic data and specific surveys involving intersections instrumented for bus priority operation. The traversal time is currently a constant in the algorithm, equal to ten seconds.

An essential phase of the BPS experiment, preceding the full-scale operation of the system, will consist of the refinement of the already stored parameters. This will come about both through the accumulation of additional data and through actual experimentation with the systems in operation. The modification of these parameters in the program is a routine matter. Should an evaluation of system data indicate that improved performance can be achieved by making the traversal time a function of link and time of day, the necessary stored tables can be provided.

5.6 SELECTION OF BPS INTERSECTIONS

Thirty-four intersections marked on the map of Figure 5-8 have been selected for the BPS experiment. These intersections were instrumented with a number of bus detectors, as shown in Table 5-3.

5.6.1 PRIMARY CRITERIA

A number of criteria were applied in the selection of the BPS intersections. The first criterion is that they be selected from among the 100 UTCS intersections where the signals will be under computer control. The second criterion is that regularly scheduled high-frequency bus routes pass through the intersections.

TABLE 5-3. BPS CONTROLLED INTERSECTIONS SUMMARY

Section	Intersection	No. Bus Detectors
1	M/Wisc.	6
	1	6
2	Wisc/Garfield	4
	Wisc./R St.	4
	Wisc./Macomb	4
	Wisc./Calvert	4
	Wisc./W Place	4
	5	20
3	Penn./18/H	6
	Penn./17	4

Table 5-3. BPS Controller Intersections Summary (Cont.)

Section	Intersection	No. Bus Detectors
	K/19	6
	K/18*	6
	I/18*	2
	I/17*	2
	Penn./19/H	4
	H/17	4
	Penn./I/21	6
	K/21	6
	K/20	6
	L/21	2
	L/20	2
	L/16	4
	L/19	2
	L/18	2
	I/16	4
	K/16	8
	H/Conn/Jackson	6
	H/16	2
	L/14	4
	K/14	8
	22	96
4	Const./19	4
	Const./17	4
	EN/19	4
	ES/18	2
	G/18	4
	F/18	4
	6	22
System Totals	34	144

5.6.2 ADDITIONAL CRITERIA

Five additional criteria were applied in selecting the intersections to be instrumented. These are described below.

A. Availability of Green Time

The effectiveness of a strategy that relies on extending the green interval by stealing time from the cross-street green interval will be limited where there is little or no excess cross-street green time available. The minimum cross-street green interval that must be maintained is usually determined by the pedestrian crossing time required. Intersections where the split already favors the bus so heavily that the cross-street green interval is at or

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* Intersections are currently inoperative as BPS due to subway construction.

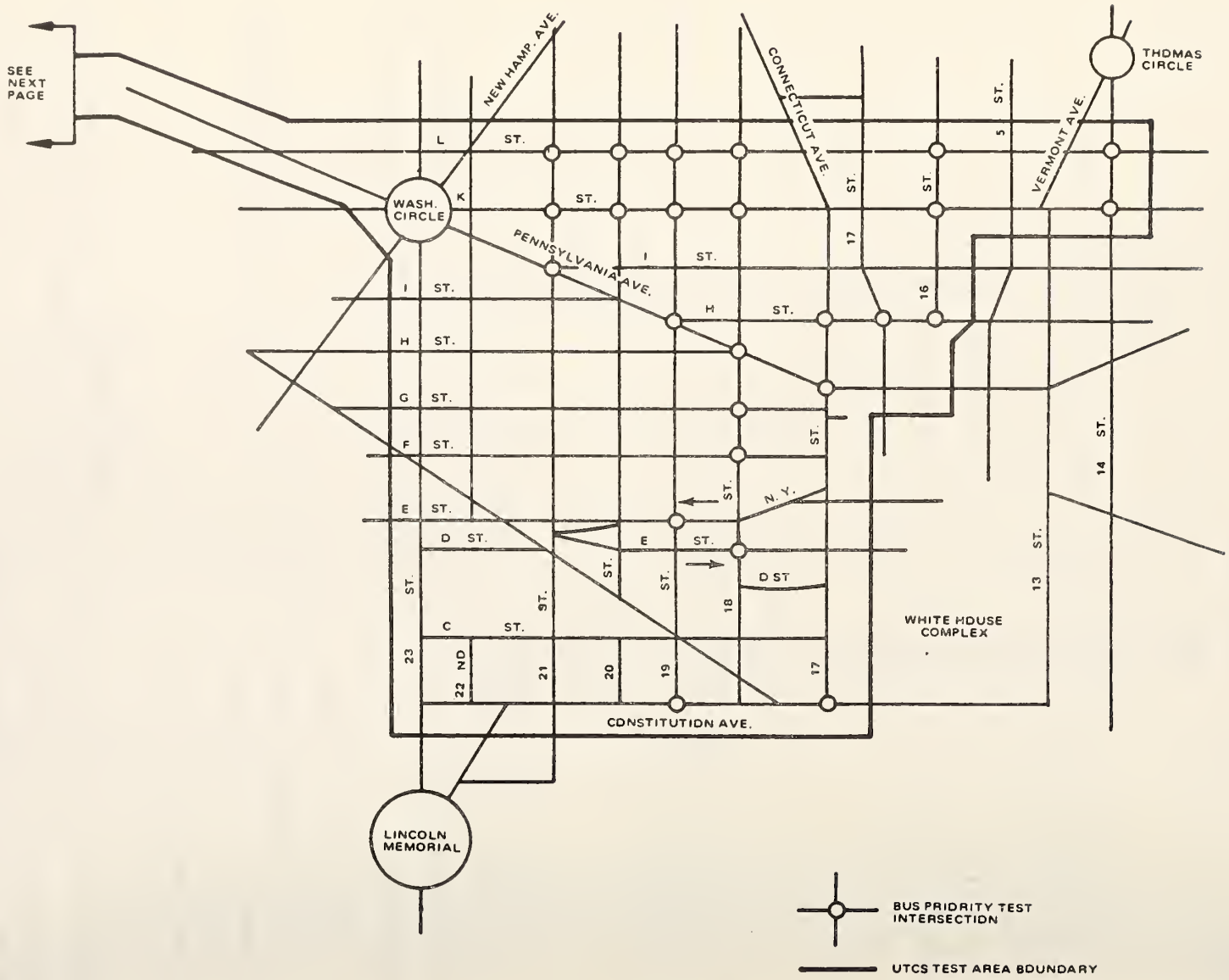

Figure 5-8. BPS Test Area (Sheet 1 of 2)

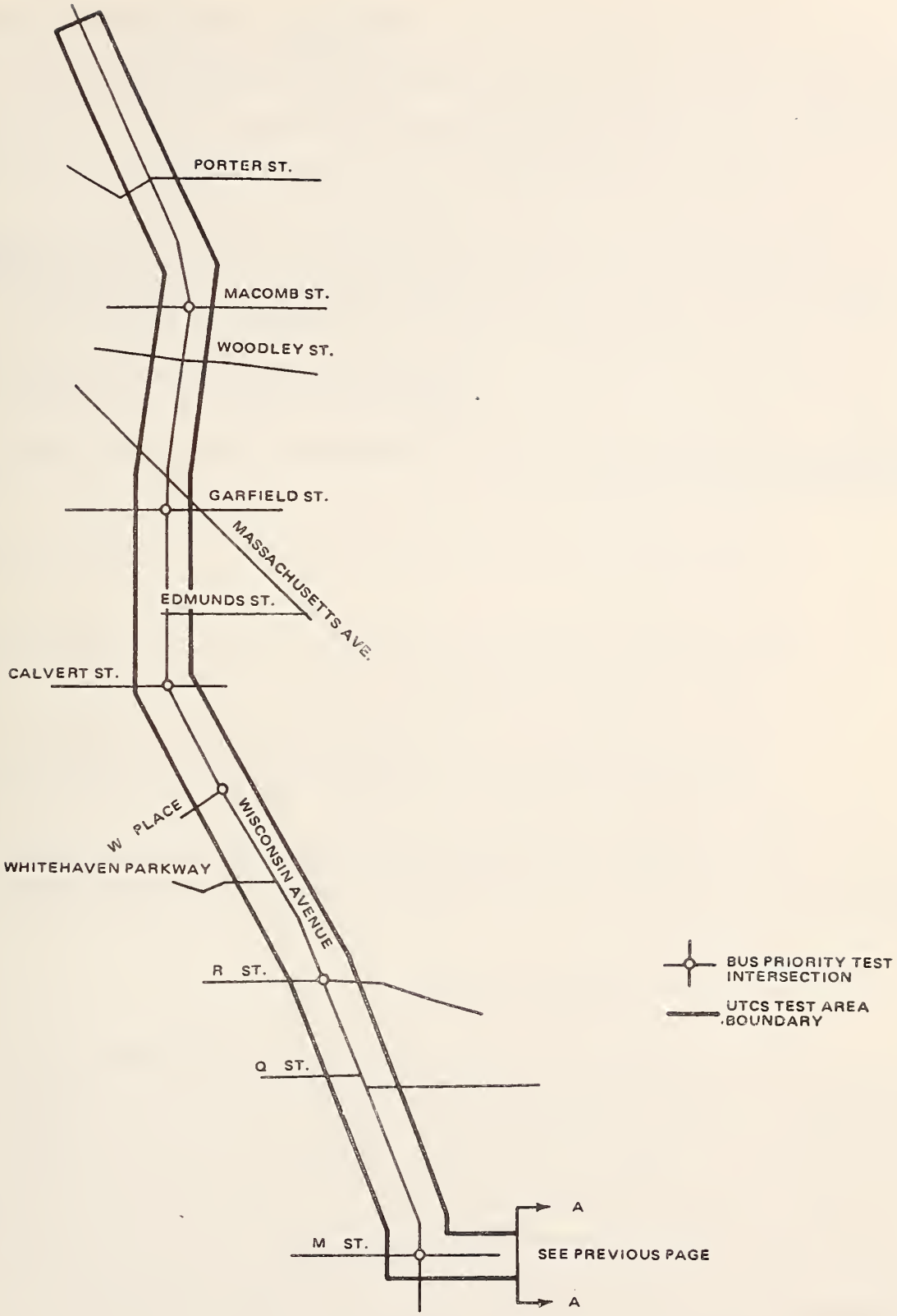

Figure 5-8. BPS Test Area (Sheet 2 of 2)

near the minimum safe limit were therefore eliminated. Typical examples are the intersections of Constitution Avenue and 20th and 21st Streets. Minimum cross-street green intervals were determined from flashing "don't walk" interval data, or from the width of the main street at intersections where there are no "walk" signs.

B. Availability of Traffic Data

The experimental nature of the BPS makes it essential that queue length data be available at all intersections. The data are to be used in the control algorithm, and to measure the effectiveness of the control strategy and the effects on traffic flow in general. These criteria would not necessarily apply to an operational bus priority system, but are essential for the test installation. Intersections where the cross-streets cannot be instrumented for queue length measurements were therefore eliminated. Other factors that preclude queue length measurement are:

- Block lengths which are too short to accommodate the standard queue detector spacing
- The presence between queue detectors of parking lot entrances and exits that cause errors in the data
- Reversible streets or lanes which could only be instrumented with a large number of detectors and a considerable increase in software complexity.

Typical examples are H Street and 18th Street where the northbound block length is too short, and K Street and 15th and 17th Streets where both 15th and 17th Streets are reversible.

C. D. C. Transit Company Participation

For convenience it has been recommended that only the buses of the D.C. Transit Company, which operates 65 percent of the buses in the test area, be equipped with bus transmitters. In order to maximize data and minimize cost, intersections which have a very low volume of D.C.T. buses were eliminated. Not every bus that passes through a test intersection is equipped with a transmitter. However, a sufficient number are equipped so that the cumulative effect of green extensions on traffic flow can be observed and so that enough data can be obtained to justify the cost of instrumenting the intersection. Examples of intersections where bus volume is low and limited to morning or afternoon rush hours only are 23rd and H Street and 23rd and I Streets.

(1) D. C. Transit Bus Assignments

D. C. Transit buses to be equipped with transmitters were selected from four divisional garages. Routes were selected which traversed the maximum number of instrumented bus zones. The number of instrumented buses allocated to each route was consistent with D. C. Transit's current assignments during A.M., P.M. and basic operating periods. Buses equipped with transmitters are also available as spares during these periods. Four hundred fifty buses have been equipped with transmitters for participation in the BPS test program. A summary of the garage and route allocations is given in Table 5-4.

D. Presence of Semi-Actuated Controllers

Intersections where semi-actuated controllers are now installed were eliminated. Here buses have green signals most of the time, so that very little data would be obtained.

TABLE 5-4. SUMMARY OF BPS EQUIPPED BUS ASSIGNMENTS

Division	Oper. Period	Penn. Ave.	Mt. Pleas.	14 St.	16 St.	Conn. Ave.	Mass. Ave.	Benning	No. Cap. St.	Glov. Pk.	Maryland	Total	Spares*
Bladensburg	A.M.	7	34	-	-	8	-	78	19	33	29	208	16
(Total Equip.)	P.M.	2	42	-	-	10	-	73	22	36	30	215	9
= 224	Basic	-	24	-	-	-	-	22	12	13	13	84	140
Northern	A.M.	-	-	35	52	-	-	-	-	-	-	87	17
(Total Equip.)	P.M.	-	-	39	54	-	-	-	-	-	-	93	11
= 104	Basic	-	-	28	12	-	-	-	-	-	-	40	64
Western	A.M.	26	-	-	-	40	24	-	-	-	-	90	32
(Total Equip.)	P.M.	34	-	-	-	43	28	-	-	-	-	105	17
= 122	Basic	17	-	-	-	17	7	-	-	-	-	41	81
Total All	A.M.	33	34	35	52	48	24	78	19	33	29	385	65
Divisions	P.M.	36	42	39	54	53	28	73	22	36	30	413	37
(450)	Basic	17	24	28	12	17	7	22	12	13	13	165	285

*Available for use on any of the applicable bus lines in each division

SECTION 6

VERIFICATION OF UTCS/BPS OPERABILITY

The UTCS functional operability was initially established at the Sperry, Great Neck, facility in conjunction with a simulation program. Operability was then verified, following installation at the Washington, D.C. site, using actual traffic.

6.1 UTCS/BPS SIMULATION PROGRAM

The Simulation Program is a computer hardware/software system, interfacing with UTCS, which served as a debugging tool for the UTCS computer program and provided representative dynamic traffic data for map and CRT display. In order to realize its objectives, the program was required to generate detector data, in real time and under operator control, which realistically represented traffic flow in a simulated street network under dynamic control of UTCS. Specifically, the program functions were to:

- Simulate traffic signal controllers responding to hold signals and advance pulses originating in the UTCS computer and, in the absence of these control signals, simulate the behavior of controllers operating in a standby mode
- Periodically update a traffic mode, simulating vehicle and bus movement within UTCS links and zones subject to input volumes, free-flow speeds, and controller signal states
- Generate vehicle detector signals and bus detector pulses representative of the passage of vehicles over each detector in conformance with simulated traffic flow
- Respond to operator action requests by displaying and changing network parameters.

6.2 UTCS/BPS WASHINGTON, D.C. INTEGRATION

The UTCS/BPS functional operability has been continuously demonstrated throughout the system installation and integration phase which began about May 1, 1972. Controllers and detectors were placed on line early in the integration program, and additional units were placed on line as they were installed. The system thus expanded progressively until the final complement of 111 controllers, 497 detectors, and 144 bus detectors was achieved.

During the integration phase, which covered a period of seven months, the system was placed on line on a day-to-day basis and was exercised in all aspects of system operation.

6.3 UTCS/BPS WASHINGTON, D.C. ACCEPTANCE TEST PROGRAM

Acceptance tests have been conducted for the purpose of demonstrating UTCS/BPS operational readiness (See Appendix E). Several preliminary runs of the various tests were made first; the tests were then conducted on a formal basis. All tests were successfully completed.

The tests included five categories:

- MOE computations, including volume, speed, occupancy, queue, stops and delay
- Computer-controlled time-of-day operation
- CIC operation
- BPS operation
- Pattern match operation.

All tests except the MOE occupancy and the pattern match tests consisted of comparisons of field and central observations. For example, for the queue test, the queue on a specified link each cycle over a 15-minute period was recorded by field observers, simultaneously with the recording of the queue indicated at central on the CRT for each cycle and on the 15-minute report encompassing the test period. The results were averaged and checked for conformance within specified limits. In the case of the occupancy test, it was not feasible to measure occupancy directly in the field. For this test, an electronic counter was used to measure detector pulse widths at central on incoming channels associated with the link under test. Occupancy was computed from these observations over a 15-minute period and was compared with the corresponding value obtained on the CRT display and 15-minute report.

The pattern match test was conducted at central with the system operating in the Traffic Responsive mode. Since a pattern match operation is performed on a section basis involving many intersections, it was not feasible to obtain the required field data. Volume and occupancy data corresponding to the links in the section were obtained from the system 15-minute report and compared with stored patterns for the system. Volume plus weighted

occupancy total differences were then computed for each pattern. It was then verified via the CRT display that the UTCS/BPS program did select the appropriate pattern. During the test which covered six 15-minute selection periods, pattern selection was made from among four stored patterns which had previously been generated off-line using system derived data and the Traffic Signal Optimization Program (SIGOP), Reference 6A.

Although the occupancy and pattern match tests were based solely on observations at central, the association and interaction of the various links and controllers involved were verified during system integration. Furthermore, the accuracy of system outputs relative to occupancy and pattern match operation was previously established by other acceptance tests. For example, occupancy is related to speed which was measured in terms of field observations. Volume outputs, which are used in the pattern match operation, were checked by field observations during previous acceptance tests.

The UTCS Acceptance Test Plan, which was used to generate the detailed acceptance test procedures, is included in Appendix E. The plan can be used as a guide in generating an acceptance test plan for a future computer-controlled traffic system patterned after the UTCS. Tolerances for the MOE tests have been omitted; they will vary in accordance with the particular application.

6.4 UTCS PATTERN GENERATION

6.4.1 INTRODUCTION

UTCS patterns have been generated using system outputs in conjuction with SIGOP and other off-line programs. Four patterns have been generated in accordance with contractural requirements for each of the four UTCS sections, covering data periods (or SIGOP optimization periods, OTP's) as follows:

Time Period	System Pattern No. Designation
0830-0945	5
0945-1130	6
1130-1300	7
1300-1530	8

A functional flow diagram of the pattern generation process used is presented in Figure 6-1. It is apparent from the figure that preliminary studies and surveys of the signalization and geometric configuration of the controlled complex is initially required. The outputs of these studies are the SIGOP parameters and the UTCS controller and link data.

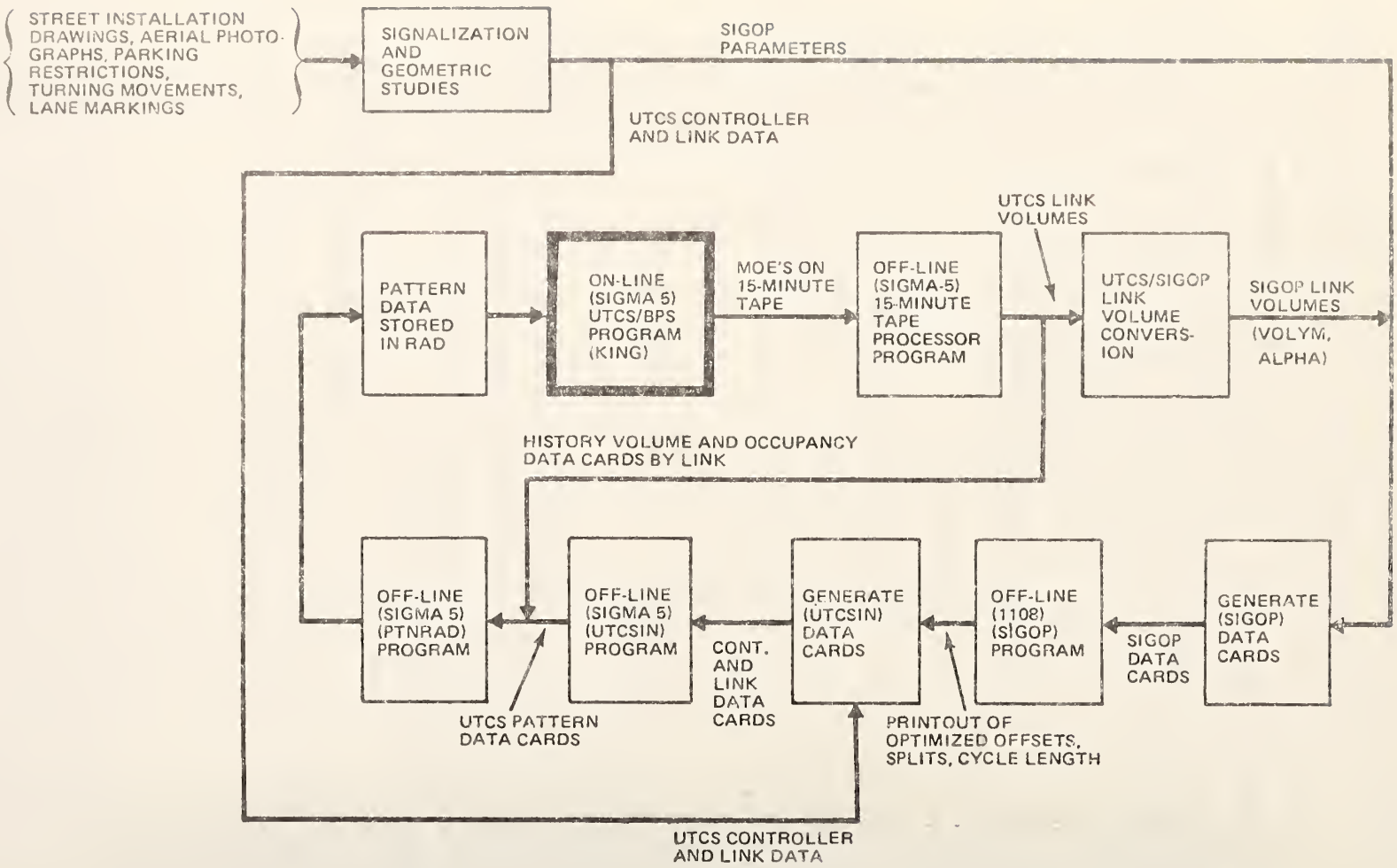
STREET INSTALLATION DRAWINGS, AERIAL PHOTOGRAPHS, PARKING RESTRICTIONS, TURNING MOVEMENTS, LANE MARKINGS
SIGNALIZATION AND GEOMETRIC STUDIES
SIGOP PARAMETERS
UTCS CONTROLLER AND LINK DATA
UTCS LINK VOLUMES
PATTERN DATA STORED IN RAD
ON-LINE (SIGMA 5) UTCS/BPS PROGRAM (KING)
MOE'S ON 15-MINUTE TAPE
OFF-LINE (SIGMA-5) 15-MINUTE TAPE PROCESSOR PROGRAM
UTCS/SIGOP LINK VOLUME CONVERSION
SIGOP LINK VOLUMES (VOLYM, ALPHA)
HISTORY VOLUME AND OCCUPANCY DATA CARDS BY LINK
OFF-LINE (SIGMA 5) (PTNRAD) PROGRAM
OFF-LINE (SIGMA 5) (UTCSIN) PROGRAM
GENERATE (UTCSIN) DATA CARDS
OFF-LINE (1108) (SIGOP) PROGRAM
GENERATE (SIGOP) DATA CARDS
SIGOP DATA CARDS
CONT. AND LINK DATA CARDS
UTCS PATTERN DATA CARDS
PRINTOUT OF OPTIMIZED OFFSETS, SPLITS, CYCLE LENGTH
UTCS CONTROLLER AND LINK DATA

Figure 6-1. UTCS Pattern Generation Functional Flow Diagram

A. SIGOP Parameters

Initially, the SIGOP network was defined for each section. The nodes of the network were made to correspond to the controlled intersections. The interconnecting SIGOP links between nodes were associated with UTCS-instrumented links.

Non-instrumented links within UTCS were associated, where possible, with an adjacent instrumented upstream or downstream link. For example, the northbound link at I and 20th Streets was associated with the northbound link at K and 20th Streets. The selection of the appropriate instrumented link for association was based on field traffic data or counts. Association was made where similar flow characteristics were indicated for both links. Where field data indicated that the flow variations for the two links were in synchronism, but only fractionally, the proportion of flow was adjusted accordingly. Where field data were not available, association was based, where possible, on geometric considerations. For non-instrumented links which could not be related to an instrumented link (for example, in a grid area where a link is too far removed from an instrumented link), field traffic flow data were used where available. UTCS intersections which do not have instrumented links and which could not be associated were not included as nodes in the SIGOP analysis, if valid field traffic data were not available.

Geographic, controller timing, and traffic data were utilized to generate the parameters associated with SIGOP links at each node, such as:

- ALANE - effective number of approach lanes
- DLANE - effective number of discharge lanes
- DSTNC - distance between stop lines, in feet
- ADVAR - advanced beginning of red, in fraction of a cycle
- DEBEG - delayed beginning of green, in fraction of a cycle
- FTRDN - fraction turning downstream; i.e., vehicles making turning movement when discharged from link, expressed as fraction of total link volume
- FTRUK - fraction of commercial vehicles (trucks and buses) on link, expressed as a fraction of total link volume

- FTRUP - fraction turning upstream; i.e., secondary flow on link, expressed as fraction of total link volume
- SPEED - link speed, punched on card in miles/hour and converted by program INPUTS to feet/second
- NUFAZ - number of phase at downstream intersection displaying green to link flow, and therefore to which link flow is assigned
- NUMPD - number of phase immediately preceding "all pedestrian" or "all red" interval
- PEDES - "all pedestrian" interval in seconds
- GREMI - minimum green plus amber time, in seconds
- AMBER - amber time, in seconds

These and other SIGOP parameters are further defined in Reference 6A.

B. UTCS Controller and Link Data

UTCS controller and link data are required to generate the SIGOP parameters described above. In addition, the data are required to generate the UTCS patterns in conjunction with the optimized SIGOP outputs of cycle length, offset and split. The controller data include controller type, starting and ending interval numbers for each phase, adjustable interval numbers and minimum adjustable interval number for each phase. The link data include the link number to controller number reference, link phase, starting green interval number, starting and ending amber interval numbers, link direction code, major link code, and volume and occupancy history values corresponding to the period for which the pattern is to be applied. The history values are obtained as output cards from the 15-minute tape processor program.

C. Off-Line 15-Minute Tape Processor Program

The 15-minute tape processor program is a FORTRAN program which reads in the 15-minute report system tape, averages the 15-minute volume and occupancy values over the desired time period for the pattern, and outputs the values, by link, on cards in the desired format for inputting into program PTNRD which stores the data into the RAD.

Printouts of the average volumes and occupancies are also obtained, which are used in obtaining the ALPHA and VOLYM input parameters for SIGOP. ALPHA is the platoon coherence or link importance factor and VOLYM is the total SIGOP link volume in vehicles per hour.

D. SIGOP Outputs

VOLYM and ALPHA values for each SIGOP link are required to complete the required input data cards for SIGOP operation. VOLYM is determined from UTCS volumes (for a single lane) by multiplying by the effective number of approach lanes (ALANE) at the intersection for the corresponding SIGOP link. ALPHA is determined in terms of the system-indicated volume and occupancy values.

SIGOP prints out optimized related pattern parameters which include offsets, splits, and cycle lengths for each intersection. These are then combined with controller and link data in generating the input cards for the UTCSIN program.

E. Off-Line (UTCSIN) Program

UTCSIN is a FORTRAN program which accepts UTCS controller and link data cards and outputs data cards which define the pattern in the format for inputting into program (PTNRAD).

F. Off-Line (PTNRAD) Program

PTNRAD is a FORTRAN program which accepts data cards which define the UTCS patterns, and stores the data in the RAD in the proper format.

6.4.2 DATA GATHERING DURING PATTERN GENERATION

The system was on line in the time-of-day mode during data gathering for the patterns described above. At that time, the time-of-day patterns stored in the RAD were a duplication of the three existing local dials. As new patterns are generated, they will replace the dial patterns for time-of-day operation. This will provide finer transitions between traffic patterns than that provided by the three-dial operation. To ensure that generated patterns are optimum, it is recommended that the pattern generation process for the patterns described above, and any additional patterns obtained in the future for other periods, be repeated after the initial system-derived time-of-day patterns are stored in the

RAD. If measure-of-effectiveness criteria for optimization, indicated by SIGOP VALUAT program printouts, are significantly enhanced for the repeated operation, the new pattern should be utilized.

6.4.3 UTCS PATTERN CONFIGURATION

The current pattern storage configuration uses a combination of local dial-duplicated and system-generated patterns, totalling eight. These are summarized in Table 6-1.

TABLE 6-1. UTCS PATTERNS CONFIGURATION

Pattern No.	TRSP	TOD	Manual	Remarks
1		1845-600	X	Duplication of dial 1
2		600-830	X	Duplication of dial 2
3		1530-1730	X	Duplication of dial 3*
4		1730-1845	X	Duplication of dial 3**
5	X	830-945	X	System-derived (SIGOP)
6	X	945-1130	X	System-derived (SIGOP)
7	X	1130-1300	X	System-derived (SIGOP)
8	X	1300-1530	X	System-derived (SIGOP)

In summary, there are eight patterns currently selectable in time-of-day operation. Four of them are duplications of the original dials, and four are system-derived. The four system-derived patterns are selectable in the Traffic Responsive mode. All eight patterns are currently selectable in the Manual Pattern mode.

Present UTCS software provides for selection from a maximum of 12 stored patterns during pattern matching operation. Matching relative to more than 12 patterns may exceed time loading capacity. However, matching to a larger number of patterns can be attained in effect, if a preliminary selection is made from groups of patterns (maximum of 12 patterns per group) which can be classified, for example, according to time of day. The two-stage operation will require a relatively minor change in the UTCS software.

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*Dial 3 for all controllers except 45, #45 in Dial 1.

**Dial 3 for all controllers except 28, #28 in Dial 2, Reset 3.

SECTION 7

OPERATION AND MAINTENANCE STAFFING

In staffing a new UTCS operation, it is recommended that presently employed traffic-oriented personnel be trained for specific tasks, where the individual's capability permits. The UTCS Traffic Control Center design and configuration is such that highly specialized computer-oriented and system-oriented personnel are not required on a full-time basis at the Control Center.

The UTCS features a highly developed, human-engineered, central complex which permits great flexibility in operation, including start-up, shutdown, surveillance of traffic, assessment of traffic situations, and detection and repair of traffic system components. These operations have been broken down into routine step-by-step procedures (Reference 6B). The operator is alerted to system malfunction by the traffic control panel, map display and CRT display. Procedures for isolating a malfunction to a particular area or equipment have been documented (Reference 6C). Repair, at central and in the field, can usually be effected on a modular replacement basis.

7.1 CENTRAL STAFFING

It is recommended that the UTCS be operated on a two-shift basis. The first shift should start at 6:30 AM and end at 3:30 PM, and the second shift should start at 3:00 PM and end at 12:00 midnight. An overlap of 30 minutes permits an exchange of information on system status. System operation is thus available during the AM and PM peak hours as well as during late-hour (11:00 PM to midnight) theatre and sporting event traffic. The system is shut down and local dial operation is in effect between midnight and 6:30 AM.

Two traffic system engineers trained in both the operation of the system and the troubleshooting of system malfunctions are recommended at central for each shift. They will be required to perform all system operational functions, isolate system equipment malfunctions at central, implement operational changes, and evaluate system operation. They are also required to communicate with and exchange information with field maintenance men in the isolation and repair of failed system field components and communications. Although system operators have the capability, through system displays and controls, to

detect computer malfunctions, it is recommended that the computers and peripherals be maintained under a separate service contract with the computer manufacturer.

A programmer, trained in FORTRAN and computer assembly language, is required on a part-time basis. His functions are to develop program modifications, and generate and store new traffic patterns. The programmer will conceivably share his time with other facilities of the traffic department utilizing computers.

7.2 FIELD STAFFING

It is recommended that controller and electronics cabinet equipments, together with vehicle and bus detectors, be maintained by the present traffic department maintenance shop staff. Two men, trained in the maintenance and troubleshooting of the field equipment, should be on call during UTCS operating shifts. Field repair should be carried out in the field on a module replacement basis, followed by repair of the modules in the maintenance shop.

7.3 STAFF TRAINING

A group at least twice as large as the number required to meet the staffing recommendations described above should be trained in each category to allow for proper scheduling of personnel to cover such contingencies as vacations, sickness, and turnover. Thus, at least eight men in the traffic department should be trained for system operation and maintenance, two men for system programming, and eight men for field maintenance.

APPENDIX A

GLOSSARY

The glossary is presented in three parts:

1. Urban Traffic Control Systems (UTCS) terms and MOE parameters
2. Bus Priority System (BPS) terms and MOE parameters
3. General terms

A discussion of the UTCS and BPS MOE parameters, together with their use in the various displays and printouts, is also given. Table A-1 provides a summary of the seven UTCS parameters. This summary lists the units of the parameters, where they are displayed, and whether they are smoothed (or filtered) quantities.

A.1 Urban Traffic Control System (UTCS) Terms

A-Phase Green - The return discrete signal from a controller which is transmitted to the computer. It is initiated at the start of the first controller timing interval, which represents the "main" street going green, and is present during the time that this phase is green. The chosen phase direction for each intersection corresponds to the direction of the "main" street traffic flow and is reflected in the intersection arrows on the map display.

Control Mode - The four modes are: Time of Day, Manual Pattern, Traffic Responsive and Standby.

Critical Intersection Control (CIC) - Adjustment of individual intersection split on a cycle-to-cycle basis as a function of green demand. Queue and volume measurements on opposing phases are utilized to determine green demand time for each phase.

Link - A lane between two adjacent intersections which is instrumented with one or more vehicle detectors.

Manual Pattern (MAN) - Mode of operation of a section where the desired operating pattern is selected by the operator by designating it by number through the Control Panel. He may select any one of a number of stored patterns for each section.

Offset - The portion of a cycle (expressed in seconds) that the start of the first controller interval is offset or displaced with respect to the master district radio pulse, or with respect to the computer reference (computer-generated start of A-Phase Green).

Pattern - Consists of stored control parameters which are read in from the Rapid Access Disc (RAD) to facilitate the operation of intersections within a section in a prescribed manner. These parameters include cycle length, offset, all interval durations for all controllers, volume and occupancy histories for all links, plus other auxiliary parameters required to operate the system. The auxiliary parameters are computed with an off-line program.

Phase - The portion of a controller cycle (expressed in seconds) during which traffic is permitted to flow. It may include one or more directions of flow.

Pre-Timed Controllers - These constitute the greatest majority of controllers in the UTCS. These controllers provide a choice of three programs of constant signal intervals in recurring cycles: Dial 1 - Basic, Dial 2 - AM Peak and Dial 3 - PM Peak.

Multi-Detector Link - A link with two or three detectors configured for the measurement of queue.

Section - A selected group of controllers which always operate in the same control mode at a given time.

Semi-Actuated Controllers - Those controllers in which the B-phase has right-of-way only when actuated by a vehicle or pedestrian.

Split - The ratio or apportionment of the total controller cycle to the various phases of traffic flow at an intersection.

Smoothed - Noise fluctuations in the data have been minimized through the use of a first-order filter.

$$\left(\bar{V}_i = \bar{V}_{i-1} + K_s \left[V_i - \bar{V}_{i-1} \right] \right)$$

Where K_s = smoothing constant empirically derived
V_i = value to be smoothed

Standby Mode - Computer control is relinquished to local dial system control for a controller, controllers in a section, or all controllers in the system. Surveillance of all detectors continues with respect to failure status and the Speed, Volume, and Occupancy MOE parameters.

System - The total of all sections in the UTCS.

Time of Day (TOD) - Mode of operation of the system or of a section wherein the pattern applicable for a particular time of day is automatically selected. The TOD pattern is read in from the RAD and checked every 15 minutes to determine when a new Time of Day pattern is to be read in. Thus, the current TOD pattern is continuously available in the computer.

Traffic Responsive (TRSP) - Mode of operation of the system or of a section where the operating pattern is based on a best match of current measured link volume plus weighted occupancy data for all links with a number of applicable stored histories. The pattern corresponding to the histories with the best match is selected. If current values are not significantly different from stored histories, the current operating pattern is not changed.

Traffic Control - When referred to a Control Panel selection, it includes all system functions exclusive of BPS and CIC operation.

Transition - A transformation period consisting of one or more cycles for smoothly transforming from one area control pattern to another, or when a controller is being transferred from standby to computer control.

Urban Traffic Control System (UTCS) - Consists of the portion of the total integrated system exclusive of BPS operation and control. It encompasses the operation of all vehicle detectors with associated links and intersections with associated controllers.

Weighted Occupancy - A parameter used in the UTCS program. It is summed with volume and the combined values are used as the criterion for a pattern match in the Traffic Responsive mode. Measured occupancy values are modified by an appropriate weighting factor such that any ambiguity associated with volume vs. density is removed when a given lane exceeds its volume carrying capacity.

Zone - The portion of a link between an upstream and a downstream detector, or between the furthest downstream detector and the intersection.

A.1.1 UTCS MOE Parameters

The UTCS Measure of Effectiveness (MOE) parameters are presented in various forms in displays and reports. They are used for analyzing traffic conditions and for

evaluating the effects of system changes such as mode, pattern, offsets and splits. The seven available parameters are:

1. Delay
2. Occupancy
3. Queue
4. Speed
5. Stops
6. Travel Time
7. Volume

The basic definitions of the UTCS MOE parameters are as follows:

Delay - Average time, beyond free flow travel time, spent by a vehicle in a link. Delay is presented in two ways; average delay of all vehicles in a link over a 15 minute period in seconds per vehicle, and total delay, in hours, of all vehicles in a link over an operating day. Values are available only for multi-detector links.

Occupancy - Percent occupancy as indicated in UTCS displays and reports. It is available for all links. For a single detector link, it constitutes the percentage of time that vehicles indicate presence at the detector. For a multi-detector link, it is computed as an average by dividing the total raw link occupancy by the number of detectors.

Queue - The sum of all vehicles, both moving and stopped, within all the zones of a link at the instant the traffic signal controlling the link turns green. Values are available for all multi-detector links.

Speed - Average speed of all vehicles in a link in miles per hour over a cycle, a 15 minute period, or over an operating day. Values are available for all links.

Stops - Total number of stops per link for a period of a cycle length, 15 minutes, or the operating day. Values are available only for multi-detector links.

Travel Time - Travel Time is presented in two ways, average time spent by vehicles in a link over a 15 minute period in seconds per vehicle; and total time, in hours, spent by all vehicles in a link over an operating day. Values are available for all links.

Volume - Volume is presented in two ways, as a rate in vehicles per hour, and as the total number of vehicles passing through the link over the operating day. Values are available for all links.

These parameters are displayed and reported in various forms. The occupancy, queue, speed, stops and volume parameters are smoothed on a controller cycle basis. The current smoothed values are listed for links associated with a particular controller via a CRT Intersection Status page selection. These smoothed values also control the link indicator lights on the map display corresponding to the parameter chosen when the Surveillance mode is selected for the map display.

All seven MOE parameters are computed on a 15 minute cycle basis. These outputs are based on 15 minute accumulations of raw data. The totals and average values are listed in the 15-Minute Report for links which differ significantly from normal stored values of volume plus weighted occupancy for the link. The 15-minute values of the delay parameter are listed on the CRT Intersection Status page and are also used to control the map link indicator lights, if the delay parameter is chosen when the Surveillance mode is selected for the map display.

The 15-minute values of all seven parameters are accumulated and, the combined total or average value as the case may be, is listed for each link in the End of Day Report. In addition, the values are combined for each section and for the total system.

A summary of the MOE parameters, indicating where and the form in which they are available is presented in Table A-1. Further discussions of the use and interpretation of UTCS MOE's in conjunction with displays and reports are given in Appendix C, Status Reports and Displays.

A.2 Bus Priority System (BPS) Terms

Bus Priority System (BPS) - The portion of the UTCS which includes the intersections which are instrumented with bus detectors and associated communications, interface hardware and BPS computer (CPU #2). The BPS is used to grant bus extensions and to evaluate BPS performance.

BPS System - When referring to a Control Panel selection, it includes all bus detectors, bus zones, and intersections instrumented with bus detectors.

TABLE A-1. SUMMARY OF UTCS MOE PARAMETERS

Parameter	Applicable Links	Smoothed on Cycle Basis	CRT and Map Displays		15 Minute Report		End of Day Report		Notes
			Listed	Units	Listed	Units	Listed	Units	
Delay	Multi-Detector	No	Yes (See Note 1)	Sec/ Vehicle	Yes	Sec/ Vehicle	Yes	Hours (See Note 6)	1. 15 minute values appear on CRT and Map Displays.
Occupancy	All	Yes	Yes	Per Cent	Yes (See Note 2)	Per Cent	Yes (See Note 2)	Per Cent	2. 15 minute and EOD values based on accumulations of raw occupancy data.
Queue	Multi-Detector	Yes	Yes	Vehicles	Yes (See Note 3)	Vehicles/ cycle	Yes (See Note 3)	Vehicles/ Cycle	3. 15 minute and EOD values are cumulative averages of the queues for the number of cycles.
Speed	All	Yes	Yes	MPH	Yes (See Note 4)	MPH	Yes (See Note 4)	MPH	4. 15 minute and EOD values based on accumulations of raw link speed data.
Stops	Multi-Detector	Yes	Yes	Vehicles/ Cycle	Yes (See Note 5)	Vehicles	Yes (See Note 5)	Vehicles	5. 15 minute and EOD values are cumulative totals of the stops for the number of cycles.

Table A-1. Summary of UTCS MOE Parameters (Continued)

Parameter	Applicable Links	Smoothed on Cycle Basis	CRT and Map Displays		15 Minute Report		End of Day Report		Notes
			Listed	Units	Listed	Units	Listed	Units	
Travel Time	All	No	No		Yes	Sec/ Vehicle	Yes	Vehicle-Hours (See Note 6)	6. End of Day Report indicates total number of hours for all vehicles.
Volume	All	Yes	Yes	Vehicles/ Hour	Yes	Vehicles/ Hour	Yes (See Note 7)	Vehicles	7. Values in End of Day Report are accumulations of total number of vehicles.

Bus Extension - The extension of the green time of a phase of traffic flow at an intersection for the purpose of permitting eligible buses through the intersection after the normal start of the red phase.

Bus Zone - The portion of the lanes between two intersections included between an upstream and downstream bus detector.

Eligible Bus - A Stop or Thru bus arriving in a bus zone during the green phase which can be helped by an extension of the green time. A Stop bus within a bus zone one second plus its loading time before the start of "amber" or, a Thru bus within a bus zone one second before the start of "amber", are considered eligible buses.

Helped Bus - An eligible bus which has been aided by virtue of the granting of a bus extension.

Preempt Extension - A mode of BPS operation in which the effectiveness criteria for granting extensions for eligible buses is bypassed or preempted. This mode is selectable through the Control Panel on a system or a bus zone basis.

Stop Bus - A bus which is scheduled to stop within a bus zone for the loading and unloading of passengers.

Thru Bus - A bus which is not scheduled to stop to load or unload passengers within a bus zone.

A.2.1 Bus Priority System MOE Parameters

The BPS measure of effectiveness (MOE) parameters are:

(a) Passenger Gain/Passenger Minutes Saved

(b) Buses Helped

(c) Bus Volume

These parameters are presented in displays and reports. The basic definitions of the BPS MOE parameters are as follows:

Passenger Gain/Passenger Minutes Saved - The benefit in passenger minutes realized by the granting of bus extensions is computed by the bus algorithm. It includes the effects of the bus zone parameters such as Passenger Load, Extension Time and the red and green time of the major phases. If an extension is granted on a given phase, passenger minutes lost on opposing phases are taken into account.

Buses Helped - The number of buses aided or granted extensions are counted for each instrumented bus zone. This includes buses granted extensions when operating in the Preempt mode, or when operating normally in conjunction with the bus algorithm.

Bus Volume - The number of buses entering a bus zone are counted. Separate counts are made of Stop and Thru buses.

The three BPS MOE parameters are computed for each activated bus zone on a cycle-to-cycle basis. The cummulative values over 15 minute intervals are displayed on the CRT BPS Intersection page (Appendix C, Figure C-7) for a selected intersection. The 15 minute totals for Passenger Gain and Buses Helped are used in conjunction with the Map Display to control the link arrows (refer to Table 4-4). The 15 minute totals of the three parameters are presented in the BPS 15-Minute Report for all bus zones. The totals of these parameters, over all 15 minute operating periods, are presented in the BPS End of Day Report.

A.3 General Terms

Cathode Ray Tube (CRT) Display Unit - A device using a cathode ray tube and associated electronics which provides an alphanumeric display of UTCS/BPS status and performance.

Central - The facility in Washington, D.C. which houses the UTCS/BPS computers, communications, display, and control equipment.

Central Processor Unit (CPU) - The portion of the UTCS Computer (CPU #1) or BPS Computer (CPU #2) which performs the logical and arithmetical functions. CPU #1 is dedicated to UTCS and all interface functions. CPU #2 is dedicated to BPS functions and UTCS/BPS raw history tape generation.

Communications - Refers to equipment at Central which provides the interface between the incoming and outgoing telephone lines and the Computer Interface Unit.

Computer Interface Unit (CIU) - The portion of the UTCS/BPS hardware which provides the interface between the UTCS Computer and external central equipments, and incoming and outgoing signals to central communications. It is also referred to as the I/O Multiplexer or MUX.

CPU Control Panels - Control panels associated with CPU #1 and CPU #2. Panel switches are manipulated during CPU start-up and shutdown operations.

District - Washington, D.C. Department of Highways and Traffic.

Discrete - A long DC signal, as opposed to a pulse.

Hexadecimal - A four digit code used by the UTCS/BPS computers for presenting binary information. Four binary bits of information are conveniently expressed by a single hexadecimal digit.

Presence - Detector "on state" or total detector pulse duration, in seconds, for a single vehicle.

Program KING - Name given to UTCS/BPS program including the Executive Routine and all supporting subprograms. Reference is made to name on TTY when starting up and releasing the program.

Radio Link - The radio receiver and associated electronics at Central providing discrete signals which are used to synchronize the UTCS generated controller cycles with those referenced by the district's master clock.

Rapid Access Disc (RAD) - Auxiliary storage device used for storing control patterns, the UTCS/BPS program, the UTCS/BPS configuration at shutdown, and the Real-Time Batch Monitor (RBM). The UTCS/BPS program and configuration are read into core memory during CPU start-up.

Teletypewriter (TTY) - A UTCS/BPS peripheral equipment used for two-way communications between the computers and the operator.

EB - A pole-mounted "electronics box", used to house remote vehicle detector electronic units and remote bus detector receivers.

CB - A large pad-mounted field cabinet, used to house local vehicle detector electronics, local bus detector receivers, communication equipment, controller adapter and controller.

f_o - The carrier frequency of a frequency shift transmitter.

f_s - The "SPACE" frequency, f_o minus 30 hertz, which results when an operating frequency shift transmitter has its SPACE Key input actuated.

f_m - The "MARK" frequency, f_o plus 30 hertz, which results when an operating frequency shift transmitter has its MARK Key input actuated. (Note: On a 3F transmitter, the MARK and SPACE Key inputs cannot be actuated simultaneously.)

BE - The "BUS ERROR" signal which results when the Carrier Detect output of the 3F receiver indicates that no signal, within the receiver bandwidth, has been detected.

BS - The "BUS STOP" signal, originated by the manual action of the bus driver, results in the detection of a MARK frequency signal by the 3F receiver.

BT - The "BUS THROUGH" signal, originated by the manual action of the bus driver, results in the detection of a SPACE frequency signal by the 3F receiver.

HOLD - A long duration pulse which is used to transfer field controllers from local dial control to Central Computer control.

ADVANCE - A 0.5 second pulse which will step the cam in a field controller, only if the HOLD signal has transferred the controller to Central Computer control.

APPENDIX B

VALID CONTROL PANEL REQUESTS

A tabulation of the valid requests for the three Control Panel sections; System Control, Map Control, and Status Display, is presented in Tables B-1 through B-3. An example of how the tables can be used to check the valid Control Panel input switching for activating an intersection for CIC operation can be seen by referring to Table B-1. CIC is selected on level 1 and CONTROLLER on level 2. The controller number is entered on the level 3 thumbwheel and the ON LINE/ACTIVATE pushbutton is selected on level 4. The ENTER pushbutton is then selected, ignoring the level 5 thumbwheel setting.

TABLE B-1. SYSTEM CONTROL REQUESTS

LEVEL #1 SELECTION	LEVELS 2-5	SYSTEM	SECTION	CONTROLLER	DETECTOR	COMM.	BUS ZONE	SYSTEM SHUT-DOWN	#3 THUMBWHEEL	TRAFFIC RESPON.	MANUAL PAT. NO.	TIME OF DAY	ON LINE/ACTIVATE	STANDBY/RELEASE	PRE-EMP ON	PRE-EMP OFF	HISTORY ON	HISTORY OFF	A-PHASE GREEN	OFF-SET	TIME EXT.	FAIL ACKNOW.	FAIL REPAIR	#5 THUMBWHEEL	ENTER
TRAFFIC CONTROL		X								X															X
TRAFFIC CONTROL		X										X													X
TRAFFIC CONTROL		X											X												X
TRAFFIC CONTROL		X												X											X
TRAFFIC CONTROL		X															X								X
TRAFFIC CONTROL		X																X							X
TRAFFIC CONTROL			X						X	X															X
TRAFFIC CONTROL			X						X		X													X	X
TRAFFIC CONTROL			X						X			X													X
TRAFFIC CONTROL			X						X					X											X

Notes

1. Level #3 thumbwheel has (4) four bcd outputs for a total of 16 outputs.
2. Level #5 thumbwheel has (3) three bcd outputs for a total of 12 outputs.

Table B-1. System Control Requests (Continued)

LEVEL #1 SELECTION	LEVELS 2-5	SYSTEM	SECTION	CONTROLLER	DETECTOR	COMM.	BUS ZONE	SYSTEM SHUT-DOWN	#3 THUMBWHEEL		TRAFFIC RESPON.	MANUAL PAT. NO.	TIME OF DAY	ON LINE/ACTIVATE	STANDBY/RELEASE	PRE-EMP ON	PRE-EMP OFF	HISTORY ON	HISTORY OFF	A-PHASE GREEN	OFF-SET	TIME EXT.	FAIL ACKNOW.	FAIL REPAIR		#5 THUMBWHEEL		ENTER
TRAFFIC CONTROL				X					X					X														X
TRAFFIC CONTROL				X					X						X													X
TRAFFIC CONTROL				X					X											X						X		X
TRAFFIC CONTROL				X					X												X					X		X
TRAFFIC CONTROL				X					X														X					X
TRAFFIC CONTROL				X					X															X				X
TRAFFIC CONTROL					X				X					X														X
TRAFFIC CONTROL					X				X						X													X
TRAFFIC CONTROL					X				X														X					X
TRAFFIC CONTROL					X				X															X				X
TRAFFIC CONTROL						X			X														X					X
TRAFFIC CONTROL						X			X															X				X
TRAFFIC CONTROL								X																				X

Table B-1. System Control Requests (Continued)

LEVEL #1 SELECTION	LEVELS 2-5	SYSTEM	SECTION	CONTROLLER	DETECTOR	COMM.	BUS ZONE	SYSTEM SHUT-DOWN	#3 THUMBWHEEL		TRAFFIC RESPON.	MANUAL PAT. NO.	TIME OF DAY	ON LINE/ACTIVATE	STANDBY/RELEASE	PRE-EMP ON	PRE-EMP OFF	HISTORY ON	HISTORY OFF	A-PHASE GREEN	OFF-SET	TIME EXT.	FAIL ACKNOW.	FAIL REPAIR		# 5 THUMBWHEEL		ENTER
C.I.C.		X												X													X
C.I.C.		X													X												X
C.I.C.			X						X					X													X
C.I.C.			X						X						X												X
C.I.C.				X					X					X													X
C.I.C.				X					X						X												X
BUS PRIORITY SYSTEM		X												X													X
BUS PRIORITY SYSTEM		X													X												X
BUS PRIORITY SYSTEM		X														X											X
BUS PRIORITY SYSTEM		X															X										X
BUS PRIORITY SYSTEM			X						X					X													X
BUS PRIORITY SYSTEM			X						X						X												X

Table B-1. System Control Requests (Continued)

LEVEL #1 SELECTION	LEVELS 2-5	SYSTEM	SECTION	CONTROLLER	DETECTOR	COMM.	BUS ZONE	SYSTEM SHUT-DOWN	#3 THUMBWHEEL		TRAFFIC RESPON.	MANUAL PAT. NO.	TIME OF DAY	ON LINE/ACTIVATE	STANDBY/RELEASE	PRE-EMP ON	PRE-EMP OFF	HISTORY ON	HISTORY OFF	A-PHASE GREEN	OFF-SET	TIME EXT.	FAIL ACKNOW.	FAIL REPAIR		#5 THUMBWHEEL		ENTER
BUS PRIORITY SYSTEM				X					X					X														X
BUS PRIORITY SYSTEM				X					X						X													X
BUS PRIORITY SYSTEM					X				X														X					X
BUS PRIORITY SYSTEM					X				X															X				X
BUS PRIORITY SYSTEM						X			X														X					X
BUS PRIORITY SYSTEM						X			X															X				X
BUS PRIORITY SYSTEM							X		X													X				X		X
BUS PRIORITY SYSTEM							X		X							X												X
BUS PRIORITY SYSTEM							X		X								X											X

TABLE B-2. MAP DISPLAY REQUESTS

LEVEL #1 SELECTION	FLOW DATA	EQUIP FAILED	OFF (SURV)		A PHASE GREEN	STATUS	FAILED	OFF (CONT)		OCCUP/PASS GAIN	VOLUME/BUS HELP	QUEUE	STOPS	SPEED	DELAY		THRESHOLD	ONE OF 10 POSSIBLE	SELECTIONS		ENTER
TRAFFIC CONTROL	X									X							X				X
TRAFFIC CONTROL	X										X						X				X
TRAFFIC CONTROL	X											X					X				X
TRAFFIC CONTROL	X												X				X				X
TRAFFIC CONTROL	X													X			X				X
TRAFFIC CONTROL	X														X		X				X
TRAFFIC CONTROL		X																			X
TRAFFIC CONTROL			X																		X
TRAFFIC CONTROL					X																X
TRAFFIC CONTROL						X															X
TRAFFIC CONTROL							X														X
TRAFFIC CONTROL								X													X

Table B-2. Map Display Requests (Continued)

LEVEL #1 SELECTION	FLOW DATA	EQUIP FAILED	OFF (SURV)		A PHASE GREEN	STATUS	FAILED	OFF (CONT)		OCCUP/PASS GAIN	VOLUME/BUS HELP	QUEUE	STOPS	SPEED	DELAY		THRESHOLD	ONE OF 10 POSSIBLE	SELECTIONS		ENTER
C.I.C.			X																		X
C.I.C.					X																X
C.I.C.						X															X
C.I.C.								X													X
BUS PRIORITY	X									X							X				X
BUS PRIORITY	X										X						X				X
BUS PRIORITY		X																			X
BUS PRIORITY			X																		X
BUS PRIORITY					X																X
BUS PRIORITY						X															X
BUS PRIORITY								X													X
DISPLAY ON (This input is not "entered")																					

TABLE B-3. STATUS DISPLAY REQUESTS

LEVEL #1 SELECTION	TRAFFIC SYSTEM FAILURE	TRAFFIC SYSTEM	CONTROLLER	TRAFFIC SYS. DET.	TRAFFIC SYS. INT.	BUS SYSTEM	BUS SYS. INT.	THUMBWHEEL	ENTER
CRT NO. 1	X								X
CRT NO. 1		X							X
CRT NO. 1			X						X
CRT NO. 1				X					X
CRT NO. 1					X			X	X
CRT NO. 1						X			X
CRT NO. 1							X	X	X
CRT NO. 2	X								X
CRT NO. 2		X							X
CRT NO. 2			X						X
CRT NO. 2				X					X
CRT NO. 2					X			X	X

Note

1. Thumbwheel has three BCD outputs for a total of 12 outputs.

Table B-3. Status Display Requests (Continued)

LEVEL #1 SELECTION	TRAFFIC SYSTEM FAILURE		TRAFFIC SYSTEM		CONTROLLER		TRAFFIC SYS. DET.		TRAFFIC SYS. INT.		BUS SYSTEM		BUS SYS. INT.		THUMBWHEEL			ENTER	
CRT NO. 2											X							X	
CRT NO. 2													X		X			X	
DISABLE FAULT RELEASE*																			
MANUAL RELEASE*																			
FLASH*																			
SUPPRESS PRINTOUT*																			

*Input is not "entered".

APPENDIX C

STATUS REPORTS AND DISPLAYS

Typical status reports and displays used by the UTCS/BPS Traffic System, are presented in this Appendix. Included are the seven CRT display pages, the 15-Minute Reports, and the End of Day Reports.

C.1 CRT Displays

The CRT display pages, together with a discussion of CRT operation and Page interpretation are presented in the following paragraphs.

C.1.1 Failure Status Page

The Failure Status page (Figure C-1) includes Traffic System and BPS equipment failures. The computer continuously monitors signals from these equipments. When a malfunction is detected the information is stored, and the status page is updated the next time that the CRT is refreshed (refreshed every 25 seconds). The most recent failure appears on the top left side of the display. An "N" will be displayed in the ACK column until the operator acknowledges the failure via a Control Panel entry. The "N" then changes to a "Y". If a failure which is listed on the status page is repaired, the operator can remove it from the list by making the proper entry on the Control Panel. The computer will automatically adjust the display to fill in any void left by the repaired item.

C.1.2 System Status Page

Figure C-2 illustrates a typical display with the system having been on line for some time and section mode changes having been put into effect. If no additional mode changes are made, the pattern numbers displayed for the sections as a function of time would be as follows:

Section 1 - may change on the 15-minute mark.

Section 2 - will not change until another operator pattern selection or mode change is made.

Section 3 - will change according to time of day.

Section 4 - will change according to time of day (this Section will, however, remain in standby).

TIME: 15:48

FAILURE STATUS

TYPE	NO	TIME	MONTH	DAY	ACK	TYPE	NO	TIME	MONTH	DAY	ACK
BDET	136	1544	MAR	02	N	COMM	210	1028	FEB	29	Y
BCOM	110	1412	MAR	02	Y	DET	122	912	FEB	29	Y
DET	33	932	MAR	01	Y	CONT	66	2201	FEB	28	Y
CONT	88	821	MAR	01	Y	BDET	27	1506	FEB	27	Y
						BCOM	31	903	FEB	27	Y

(1) ALL NORMAL ____

(2) TRUNCATED LIST - TOTAL NUMBER = 42 (3)____

Type Code:
- BDET - Bus Detector
- BCOM - Bus Detector Communication
- COMM - Traffic System Detector Communication
- CONT - Controller
- DET - Traffic System Detector

Acknowledge Code:
- Y - Yes
- N - No

NOTES:
1. "ALL NORMAL" is printed out if no equipments are found in a failed condition.
2. Printed out if number of failed items exceeds CRT page capacity (38 failures)
3. Number of system failures.

Figure C-1. CRT Failure Status Page

TIME: 12:24

SYSTEM STATUS

HISTORY OFF

SECT.	TIME (1)	DESIRED MODE (2)	ACTUAL MODE (3)	PATTERN NO. (4)	CIC IN OP. (5)	BPS IN OP. (5)	FAILURES DET. (6)	FAILURES CONT. (6)
1	0905	TRSP	TRSP	7	2	1	0	0
2	1003	MAN	MAN	8	5	3	1	0
3	0905	TOD	TOD	5	14	12	3	0
4	1102	STBY	STBY	1 (7)	0	0	1	4

Mode Code: STBY - Standby

TRSP - Traffic Responsive

MAN - Manual Pattern

TOD - Time Of Day

History Code: ON - History On

OFF - History Off

NOTES:
1. Time of mode change request.
2. Mode requested by operator at time shown.
3. Current operating mode of Section.
4. Current pattern being imposed or transitioned to.
5. Indicates all controllers selected for CIC or BPS which are not inhibited.
6. Total number of controller and detector failures in each Section. Detector failures include both vehicle and bus detectors and communications failures.
7. When mode is Standby, number indicates current valid TOD pattern.

Figure C-2. CRT System Status Page

The CIC In Operation and BPS In Operation totals will change, if and operator selection via the control panel is made or, if operation is inhibited due to the detection of related malfunctions. The failure totals are continuously updated.

C.1.3 Controller Status Page

The Controller Status page (Figure C-3) indicates the controllers, by number, which are in standby, or have failed, or have been selected and operating as a CIC, or have been selected for CIC operation but are inhibited at this particular time of day. If no controllers fall within these categories, "ALL NORMAL" is printed out.

C.1.4 Detector Status Page

The Detector Status page (Figure C-4) indicates the Traffic System detectors, by number, which have failed or are in standby. Detector failures are of two types; detector electronics, which are coded "D", and detector communications, which are coded "C". (Refer to paragraph 2.7.2 for a discussion of the criteria for determining these failures.)

C.1.5 Intersection Status Page

The Intersection Status page (Figure C-5) presents the operating status of a controller or intersection, data corresponding to its current operating pattern, and its associated link MOE parameters. The Queue, Stops and Delay parameters are displayed for multi-detector links only. The display lists the associated section and links by number, plus link phase and direction. All controller interval durations for the current pattern are listed (provision for up to 16 intervals).

The Intersection Status page is used to determine and monitor the effects of operator and system changes such as split changes, offset changes, and pattern changes.

A split change can be made by the operator by adjusting the A-Phase Green duration or by the system by virtue of CIC operation. In either case, the operation can be monitored by observing changes in the interval durations. For example, if the operator entered a split change (A-Phase Green set for 30 seconds), the intervals indicated in Figure C-5 would change to: 30.0, 4.0, 42.0 and 4.0 at the start of the next controller cycle. The effects of the changes can also be monitored by relating the effects on the link MOE parameters.

TIME: 16:03

CONTROLLER STATUS

9C	10C	11S	12C	15C	17C	31C	33I	40I	41C
42F	45C	49C	50C	53C	54C	55C	57C	59C	60C
61I	65C	66I	68C	69C	70C	72C	73C	76C	77C
82C	84C	85C	87C	88I	89C	91C	93C	94C	97C
99C	100C	115C	120C	121C	123C	-			

(1) ALL NORMAL____

Status Codes: C - Operating as a CIC

I - CIC Inhibited

F - Failed

S - Standby

NOTE: 1. "ALL NORMAL" is printed out when all controllers are on-line and none have been selected for CIC operation.

Figure C-3. CRT Controller Status Page

TIME: 16:10

INTERSECTION STATUS

CONTROLLER NUMBER 12

SECTION NO.	2	OFFSET (ACTUAL)	60.0	MASTER SYNC.	Y
CIC STATUS	ACT	MIN. A-PHASE GR.	28.0	A-PHASE GR.	51.0
BPS STATUS	ACT	OFFSET (ENTRY)	60.0	B-PHASE GR.	29.0
CONT STATUS	OL	CYCLE LENGTH	80.0	C-PHASE GR.	.0

INTERVAL DURATIONS (SECONDS)(1)

1) 47.0 2) 4.0 3) 25.0 4) 4.0

LINK NO	LNK PHASE	LNK DIR	OCCUP PCT	VOLUME VPH	SPEED MPH	QUEUE VEH	STOPS NO.	DELAY SEC
36	A	N	4	272(2)	20	6	6	26
38	A	S	17	480 (3)	18	8	8	21
35	B	W	15	168	19	7	8	12
37	B	E	5	122	13	3	4	8

CIC Status Code:
- NI - Not Instrumented
- INH - TOD or Malfunction Inhibited
- ACT - CIC Activated
- REL - CIC Released
- THLD - CIC Operating Above Threshold

BPS Status Code:
- NI - Not Instrumented
- ACT - BPS Activated
- REL - BPS Released BPS Inhibited

Controller Status Code:
- OL - On line
- STBY - Standby
- FAIL - Failed

Link Phase Code:
- A - A Phase
- B - B Phase
- C - C Phase
- D - D Phase

Link Direction Code:
- N - Northbound
- NE - Northeast Bound
- E - Eastbound
- SE - Southeast Bound
- EO - Eastbound Exit Link
- S - Southbound
- SW - Southwest Bound
- W - Westbound
- NW - Northwest Bound
- WO - Westbound Exit Link

Master Synch Code
- Y - Yes
- N - No

NOTE:

1. Provision for up to 16 intervals.
2. "NOT INSTRUMENTED" is printed out if the intersection does not have an instrumented link.
3. "LINK INOPERATIVE" is printed out in row corresponding to the link, if a failure associated with the link occurs.

Figure C-5. CRT Intersection Status Page

An operator offset change can be monitored by observing the actual offset after a change is made. For example, if the operator entered an offset of 30 seconds the actual offset indicated in Figure C-5 would incrementally increase by six seconds each cycle until the last increment will make the actual offset equal to the desired operator offset. The computer can either increase the offset by increments of six seconds or reduce it by increments of three seconds each cycle. The quickest path is automatically chosen. For this example the change from a 60 second to a 30 second offset requires ten cycles in reducing increments whereas only nine cycles in increasing increments.

During a pattern change, when a controller is in transition, the Link Data portion of the display is blanked out and the legend "CONTROLLER IN TRANSITION" is printed out. The new pattern data is displayed during the transition cycles. CIC and BPS operation is inhibited during the transition cycles and the display will accordingly indicate this. The changes in the interval durations are displayed during transition cycles. Offset changes, however, are not displayed until Transition has been completed.

If a controller is placed in standby, after having previously been on-line, the Intersection Status page will display the pattern data which was applicable before it was placed in standby. Link data will continue to be displayed but multi-detector links will be limited to Occupancy, Volume, and Speed MOE parameters. If a controller is in standby and was not brought on-line, the pattern data will be blanked out but the link data for all links will be displayed but limited to Occupancy, Volume, and Speed MOE parameters.

The Master Synch "YES" or "NO" legend indicates whether the controller cycles under computer control are synchronized with the District's master clock. The "NO" indication is not indicative of computer out-of-tolerance timing accuracy. The controller is not dropped from computer control if a "NO" is indicated. Refer to paragraph 2.2.4A, B for details on the operation of controller cycle synchronization.

C.1.6 BPS System Status Page

The BPS System Status page presents the BPS system status by section and by intersection. Figure C-6, a typical display, indicates that the BPS was last activated at 3:17 PM and that the total system was activated, since the "TIME" is the same for all UTCS sections. The "ACTIVE INTER" column lists the number of intersections that are actually operating as bus intersections. Operating totals exclude individual intersections which have been selected by the operator for BPS operation but are inhibited. The "FAILURES" column totals the bus detector and communication failures for each section.

TIME: 8:05

BPS SYSTEM STATUS - BY SECTION

SECTION	MODE	TIME ON	ACTIVE INTER.[3]	FAILURES
1	ACT	1517	1	0
2	ACT	1517	3	1
3	ACT	1517	15	0
4	ACT	1517	2	0

BPS SYSTEM STATUS - BY INTERSECTION

10B	12I	17B	40I	42I	45I	49I	54B	55B	57B
59B	60I	66I	68B	70B	72B	73B	76B	77B	82B
84B	85B	88I	91B	93B	94P[2]	97I	99I	115B	120X[1]
121B	123B								

Status Code:
- B - BPS Operating
- I - BPS Inhibited By CIC Operation or TOD
- P - BPS Operating in Preempt Mode
- X - BPS Released

Mode Code:
- ACT - Activated
- REL - Released

NOTES:
1. An "X" code signifies that the intersection has been released by the operator via the control panel or by the computer as a result of an associated bus detector or communication malfunction.
2. At least one of the bus zones at the intersection has been preempted.
3. The total possible number of intersections in operation for Sections 1, 2, 3 and 4 are 1, 5, 20 and 6 respectively.

Figure C-6. CRT BPS System Status Page

Listed in the intersection portion of the display (in order of intersection number) are the total of the UTCS intersections which are instrumented for bus operation. Next to each intersection number is its current bus operation status code. Note that an "X" indicates that the intersection has either been released by the operator via the Control Panel or by the computer as a result of an associated bus detector or communication failure.

C. 1. 7 BPS Intersection Page

The BPS Intersection page presents the individual bus intersection parameters as well as the performance data (Figure C-7). The Load Times and Passenger Loads, by Zone, are intersection parameters which are used in the bus algorithms for the determination of bus extensions. Values vary according to the time of day and are so updated. The values listed in the "EXT. SEC" column are the extensions, in seconds, which will be granted to eligible buses for the corresponding zone. The permissible extensions depend on the pattern in effect for the UTCS section which includes the bus intersection displayed. The values are accordingly updated when a pattern change is made.

The performance data are presented as cumulative totals over 15 minute periods. The data is accumulated on a cycle-by-cycle basis. The cycles are counted and the number over which the cumulative totals correspond are listed in the "NUMBER CYCLES" column. At the end of the 15 minute period, the cycle count as well as the performance data, are initialized to zero. The indicated volumes are the total cumulative number of "Stop" and "Thru" buses counted in the 15 minute period. "ELIGIBLE" and "Helped" buses as well as "Stop" and "Thru" buses are defined in the Glossary, Appendix A. The "Passenger Minutes Saved" parameter is based on the "Passenger Load" parameter for the zone, the extension time, and the red and green time for the major phases at the intersection.

C. 2 15-Minute Report

The 15-Minute Report includes system status and performance reports under the following headings:

(a) Changes Since Last Report

(b) UTCS/BPS Failure Status

(c) UTCS Controller Status

TIME: 10:12

STATUS: ACT BPS INTERSECTION NO. 82

ZONE NO	DIREC.	LOAD TIME SEC	PSG LOAD	EXT. SEC.	PREEMPT EXT.
45	N	20	30	10	OFF
46	S	20	30	10	OFF

BPS PERFORMANCE DATA

ZONE NO	NUMBER CYCLES	EXT. GNT.	VOLUME STOP	VOLUME THRU	ELIGIBLE STOP	ELIGIBLE THRU	HELPED STOP	HELPED THRU	PSG-MIN SAVED
45	6	3	4	7	2	5	2	4	93
46	6	2	2	2	1	2	1	1	27

Direction Code:

N - Northbound
S - Southbound
NE - Northeast Bound
SW - Southwest Bound
E - Eastbound
W - Westbound
SE - Southeast Bound
NW - Northwest Bound

Status Code:

REL - Intersection released by operator for BPS operation, or by computer due to associated malfunction.

ACT - Intersection activated by operator for BPS operation.

INH - Intersection inhibited for BPS operation after having been activated by operator.

Figure C-7. CRT BPS Intersection Status Page

(d) UTCS Detector Status

(e) UTCS System Status

(f) UTCS System Performance Report

(g) BPS System Status

(h) BPS 15-Minute Section Summary

(i) BPS 15-Minute Zone Summary

The 15-Minute Report is printed out automatically on the 15-minute mark when CPU #1 is on-line. The printout can be suppressed by an operator request on the Control Panel. Operator changes will, however, continue to be accumulated and will be printed out at the next unsuppressed period or when 45 actions are logged, whichever occurs first.

C.2.1 Changes Since Last Report

This report lists all of the changes that the operator has made since the last report. Figure C-8 illustrates a typical report showing a total of six system changes. A complete listing of the possible type and change codes which may be included in the report follows.

Type Codes

BCOM - BPS Detector Communications

BDET - BPS Detector

BZON - BPS Zone

CONT - Controller

DCOM - Detector Communications

DET - Detector

SEC - Section

SYS - System

Change Codes

BPOF - BPS Off

BPON - BPS On

CCOF - CIC Off

CCON - CIC On

EX IN - Extension

FACK - Failure Acknowledge

HOFF - History Record Off

HON - History Record On

MAN - Manual (Pattern Number also recorded)

OFST - Offset

ONLN - On Line

PROF - BPS Preempt Off

PRON - BPS Preempt On

REPR - Repair

SPLT - Split

STBY - Standby

TOD - Time of Day

TRSP - Traffic Responsive

Note that a zero is indicated in the "NUMBER" column corresponding to a system change since a number here is not applicable.

C. 2. 2 UTCS/BPS Failure Status

This report (Figure C-9) lists all of the UTCS/BPS failures in chronological order with the latest item on the bottom of the list. Provision is made for a maximum listing of 200 failures.

UTCS/BPS 15 MINUTE STATUS AND PERFORMANCE REPORT

DATE DEC 07 72 TIME 1445

CHANGES SINCE LAST REPORT

TIME	TYPE	NUMBER	CHANGE	
1440	SEC	1	MAN	3
1441	SEC	2	TRSP	
1441	DC9M	396	REPR	
1441	DC9M	466	REPR	
1442	BDET	137	REPR	
1443	DC9M	90	REPR	

Figure C-8. UTCS/BPS 15-Minute Status Changes Since Last Report

*** UTCS/BPS FAILURE STATUS ***

TYPE	NUMBER	TIME	MONTH	DAY	ACK
BDET	137	1442	DEC	07	N
C0MM	414	1437	DEC	07	N
DET	366	1431	DEC	07	N
BC0M	115	1431	DEC	07	N

Figure C-9. UTCS/BPS Failure Status Report

```
                                *** UTCS CONTROLLER STATUS ***

   9C     10C     11C     12C     15C     17C     31I     33C     40C     41C     42C     45C     49C     50C
  53C     54C     55C     57C     59C     61C     66C     68C     69C     70C     72C     73C     76C     77C
  82C     84I     85C     87C     88C     89C     91I     93C     94C     97C     99C    100I    115I    120C
 121I    123C
```

Figure C-10. UTCS Controller Status Report

*** UTCS DETECTOR STATUS ***

366D 414C

Figure C-11. UTCS Detector Status Report

*** UTCS SYSTEM STATUS ***

HISTORY OFF

SECTION	TIME	DESIRED MODE	ACTUAL MODE	PATTERN NO.	CIC IN OPER	BPS IN OPER	FAILURES DET	FAILURES CONT
1	1440	MAN	MAN	3	2	0	0	0
2	1441	TRSP	TOD	8	6	2	1	0
3	1429	TOD	TOD	8	21	13	3	0
4	1429	TOD	TOD	8	9	5	0	0

Figure C-12. UTCS System Status Report

The Type and Acknowledge codes are the same as those given for the CRT Failure Status Page (Figure C-1).

C.2.3 UTCS Controller Status

This report (Figure C-10) is essentially a reproduction of the CRT Controller Status Page (Figure C-3). Note that the table is a blank if all controllers are on-line and none have been selected for CIC operation.

C.2.4 UTCS Detector Status

This report (Figure C-11) is essentially a reproduction of the CRT Detector Status Page (Figure C-4). Note that the table is a blank if all detectors are on-line system.

C.2.5 UTCS System Status

This report (Figure C-12) is essentially a reproduction of the CRT System Status Page (Figure C-2). The printout presents the system status at the end of the last 15-minute period. Note in the sample report that sections 3 and 4 were selected for TOD operation, section 1 for Manual Pattern 3 operation, and section 2 for Traffic Responsive operation during the last 15 minutes. The actual mode of section 2 will be Traffic Responsive during the next 15-minute period.

C.2.6 UTCS System Performance Report

The UTCS System Performance Report (Figure C-13) prints out the MOE parameters for those links which differ significantly from history values of volume and occupancy. In normal operation, valid history values are obtained and stored on the RAD, the report then lists only those links which exhibit volumes and occupancies which differ from the history values by more than a predetermined tolerance. Thus, out-of-tolerance links will be pinpointed for further observation and surveillance. The sample report (Figure C-13) lists all UTCS links since the volume and occupancy threshold values have been adjusted to force the printout of all link data. Normally only the out-of-tolerence links would be included in the printout. Note that the Queue, Stops, and Delay parameters are printed out only for multi-detector links. An "H" following the link number indicates that a detector on the link has failed and listed parameters are history values. An asterisk (*) following the link number indicates that the controller associated with the link is in standby.

C.2.7 BPS System Status

This report (Figure C-14) is essentially a reproduction of the CRT BPS System Status display (Figure C-6) except that the number of intersections in each section which are operating as active BPS intersections, operating in a pre-empt mode, or inhibited is indicated.

UTCS SYSTEM PERFORMANCE REPORT

OUT OF TOLERANCE LINK NUMBER	HISTORY VOL (VEH)	HISTORY ACC (PCT)	CURRENT CUMULATIVE MOE VOL (VPH)	ACC (PCT)	QUEUE (VEH/CYCLE)	STOPS (NO.)	AV.SP. (MPH)	TRAV.TIME (SEC/VEH)	DELAY (SEC/VEH)
1	1	0	644	10			22	7.8	
2	1	0	308	7	1	13	25	10.3	1
3	1	0	388	34	4	30	19	31.4	19
4	1	0	352	5			21	9.6	
5	1	0	184	11	2	30	22	32.4	26
6	1	0	244	15			17	15.8	
7	1	0	420	18	2	17	20	25.0	14
8	1	0	280	19	5	39	17	39.6	31
9	1	0	12	2			3	96.6	
10	1	0	460	25	7	33	16	38.2	22
11	1	0	280	20	6	41	16	46.8	31
12	1	0	352	7			23	12.9	
13	1	0	376	8			19	13.7	
15	1	0	488	8			21	7.7	
16	1	0	304	10			20	15.3	
17	1	0	140	2			23	1.6	
18	1	0	292	4			24	6.9	
19	469	7	492	9			23	13.5	
20	369	10	380	9	3	18	26	18.0	9
21	400	6	440	7	1	11	24	7.5	2
22	153	2	120	2			19	13.6	
23	71	10	12	0			46	6.7	
24	440	10	504	15	4	29	25	20.6	9
25	497	15	456	11	3	21	23	18.3	8
26	118	8	108	11	2	15	17	31.9	24
27	429	11	492	13	4	35	21	20.9	10
28	97	5	84	4	1	14	24	46.6	41
29	497	15	24	0			24	7.7	
30	336	16	284	15	1	17	18	16.4	9
31	109	5	88	2	2	15	24	36.6	31
32	350	4	384	5	2	14	33	10.6	4
33	263	5	268	6	2	15	19	18.5	11
34	269	5	272	5	1	7	26	11.1	2
35	181	12	176	11	2	23	19	27.7	20
36	445	15	404	12	2	12	21	9.8	3
37	103	6	100	11	2	19	18	36.6	29
38	469	13	428	10	4	43	21	16.4	10
39	130	7	144	8	1	17	25	20.4	15
40	614	20	604	24	5	45	19	11.6	4
41	151	9	176	9	3	32	14	48.6	38
42	505	18	412	16	2	24	21	10.3	3
43	209	13	208	12	1	13	21	10.8	4
44	552	11	524	13	3	37	23	12.2	6
45	209	13	208	15	1	14	20	18.7	12
46	407	18	412	18	4	48	18	23.3	16

Figure C-13. UTCS System Performance Report (Sheet 1 of 6)

CURRENT CUMULATIVE MOE

OUT OF TOLERANCE LINK NUMBER	HISTORY VOL (VEH)	HISTORY OCC (PCT)	VOL (VPH)	OCC (PCT)	QUEUE (VEH/CYCLE)	STOPS (NO.)	AV.SP. (MPH)	TRAV.TIME (SEC/VEH)	DELAY (SEC/VEH)
47	434	8	704	16	4	41	21	9.6	3
48	96	5	132	9	2	19	16	35.0	26
49	423	9	476	8	1	11	27	6.2	1
50	125	3	236	3			26	9.7	
51	140	3	152	4			16	4.3	
52	308	4	344	5			24	13.0	
53	229	3	264	4			25	12.2	
54	249	13	268	21			16	17.9	
55	139	15	92	1			29	5.6	
56	370	8	368	6			23	10.4	
57	139	3	140	3			20	13.9	
58	344	8	364	6			23	5.2	
59	205	4	228	6			17	1.9	
60	155	8	216	14			17	10.0	
61	119	7	120	3			18	11.6	
62	59	12	436	13	4	32	22	26.6	15
63	360	13	420	14	3	23	19	29.9	17
64	131	4	160	4			14	9.9	
65	498	13	484	11	2	17	23	14.0	4
66	157	10	308	8	1	8	22	10.6	2
67	351	17	336	27	5	22	14	36.4	18
68	253	12	536	29	7	28	14	35.5	18
69	350	12	444	11	2	12	21	13.4	3
70	498	13	192	12			21	10.5	
71	77	10	0	0			0	.0	
72	417	21	488	19	3	21	17	21.6	7
73	287	11	232	9	1	9	27	9.3	4
74	448	27	480	33	4	28	16	30.6	18
75	424	12	464	13	5	48	24	22.8	13
77	315	18	284	14	5	38	19	33.3	20
78	434	17	508	38			11	8.1	
79	207	5	256	24	3	27	15	31.6	17
80	337	15	368	14	2	25	21	20.4	8
81	481	16	576	14			18	11.3	
82	452	14	420	19	4	36	16	23.1	10
83	207	5	144	3			20	11.1	
85	129	18	276	5			20	10.3	
86	268	18	300	28			12	23.7	
87	235	6	288	8			16	11.6	
88	383	10	328	10	1	17	22	8.9	2
89	413	21	476	17	3	26	19	26.0	13
90	359	27	372	9	1	14	20	11.3	4
91	218	5	324	6			22	14.3	
92	434	18	396	24			12	6.3	
93	557	18	436	22	2	28	16	18.5	6

Figure C-13. UTCS System Performance Report (Sheet 2 of 6)

OUT OF TOLERANCE LINK NUMBER	HISTORY VOL (VEH)	HISTORY OCC (PCT)	CURRENT CUMULATIVE MOE VOL (VPH)	OCC (PCT)	QUEUE (VEH/CYCLE)	STOPS (NO.)	AV.SP. (MPH)	TRAV.TIME (SEC/VEH)	DELAY (SEC/VEH)
95	148	15	296	11	2	15	23	18.6	8
96	221	13	276	23			16	17.1	
98	125	25	496	16	6	33	19	26.2	14
99	380	22	372	21	3	30	16	20.6	12
100	35	2	56	1			17	16.7	
102	54	1	36	2			10	28.3	
104	443	21	448	22	8	60	19	30.6	17
105	334	19	296	13	2	22	22	17.4	11
106	291	25	308	25			13	19.6	
107	517	13	524	13			21	4.6	
108	345	9	456	13	2	18	26	14.0	5
109	249	4	348	8	2	13	30	12.7	4
110	249	25	400	24	4	27	20	35.6	25
111	345	9	496	12	1	13	23	7.7	2
112	187	14	304	9	1	11	19	16.2	6
113	21	6	248	4			22	9.8	
114	281	10	288	16	5	52	20	30.4	18
116	416	6	420	15			23	7.3	
117	494	17	604	23			19	16.3	
118	75	1	100	1			37	8.2	
119	262	3	292	4			27	11.3	
120	369	21	380	17			15	13.9	
121	144	3	108	3			23	7.1	
122	367	7	372	9			19	6.6	
123	316	8	516	9			19	12.0	
124	57	19	244	7	4	51	24	42.8	32
125	723	23	676	18	5	38	20	19.5	7
126	428	11	464	11			17	11.9	
127	91	10	496	22	4	26	15	22.6	8
128	361	16	452	10			18	11.4	
129	361	16	300	15	3	18	18	31.9	18
130	540	15	488	10			19	14.8	
131	183	5	176	3			21	10.1	
132	448	9	568	14			15	17.9	
133	268	14	300	8			18	17.1	
134	502	21	584	12			17	14.2	
135	269	10	288	8	2	18	23	22.8	14
136	239	3	188	2			29	7.8	
137	440	21	476	19	4	41	18	22.3	9
138	273	14	260	12	3	14	18	27.9	14
139	428	13	408	11			18	17.0	
140	372	19	400	9			17	12.2	
141	259	6	444	8			21	10.1	
142	491	9	588	9			23	9.1	
143	538	22	612	17			14	20.9	

Figure C-13. UTCS System Performance Report (Sheet 3 of 6)

UTCS SYSTEM PERFORMANCE REPORT

OUT OF TOLERANCE LINK NUMBER	HISTORY VOL (VEH)	HISTORY ACC (PCT)	CURRENT CUMULATIVE MOE VOL (VPH)	ACC (PCT)	QUEUE (VEH/CYCLE)	STOPS (NO.)	AV.SP. (MPH)	TRAV.TIME (SEC/VEH)	DELAY (SEC/VEH)
144	135	6	104	12			21	14.3	
145	522	12	456	20			16	14.3	
146	117	10	440	17	4	27	18	24.5	12
147H	634	24	616	23	0	0	0	0	0
148	557	32	552	50			10	21.1	
149	400	12	388	12	5	45	19	28.1	17
150	315	5	280	6			21	10.4	
151	405	17	444	26	3	20	15	23.6	7
152	405	17	536	11			18	11.1	
153	486	28	520	40	6	64	12	26.8	5
154	133	11	460	36	4	45	14	30.6	13
155	207	5	32	1			16	13.5	
156	337	15	372	17			16	8.1	
157	207	5	292	25	3	24	16	25.3	13
158	373	20	372	32	6	41	15	38.5	22
159	359	20	272	16	4	30	13	56.3	42
160	421	7	420	20	3	24	16	26.4	11
161	338	21	304	39	6	54	10	41.8	22
162	380	9	424	10			19	4.4	
163	259	6	404	22	3	21	22	20.8	12
164	421	7	360	12	4	28	22	18.9	7
165	213	6	172	26			14	16.3	
166	232	4	220	5			17	14.4	
167	315	15	188	6			16	14.3	
168H	257	32	200	29	0	0	0	0	0
169	354	22	396	25			14	14.8	
170	102	8	244	23	4	44	17	43.8	36
171	469	10	316	9	1	20	19	12.9	4
172	254	7	568	12			19	7.7	
173	99	5	128	9	4	30	15	54.8	38
174	315	15	296	14	2	7	16	20.6	7
175	411	13	428	15	3	30	18	16.9	9
177	982	53	380	12	4	27	16	25.3	13
178	371	27	428	27			18	6.9	
179	319	7	296	6			18	13.4	
180	481	15	464	9			18	10.2	
181	336	14	484	7			29	9.6	
183	443	15	464	19	3	0	21	17.8	7
184	371	26	412	29	2	15	16	17.4	9
185	292	14	300	14	2	0	20	19.8	7
186	336	12	388	13	1	16	22	15.1	4
187	424	9	468	18	1	21	17	13.4	2
188	231	31	260	29			14	15.6	
189	129	2	264	9	1	9	21	17.4	6
190	261	9	352	27	3	33	14	30.2	16

Figure C-13. UTCS System Performance Report (Sheet 4 of 6)

UTCS SYSTEM PERFORMANCE REPORT

OUT OF TOLERANCE LINK NUMBER	HISTORY VOL (VEH)	HISTORY OCC (PCT)	CURRENT CUMULATIVE MOE VOL (VPH)	OCC (PCT)	QUEUE (VEH/CYCLE)	STOPS (NO.)	AV.SP. (MPH)	TRAV.TIME (SEC/VEH)	DELAY (SEC/VEH)
191	175	8	420	18	3	23	19	21.6	10
192	344	15	264	21	3	12	13	23.5	8
193	495	10	504	12			17	7.9	
194	261	9	340	13	3	26	22	24.8	15
195	21	0	260	3	1	15	26	10.7	5
196	515	25	36	0			25	7.4	
197	226	9	80	3	0	3	9	32.4	3
198	307	14	296	11	2	25	30	20.1	12
199	316	4	340	9	2	17	30	16.3	8
200	316	4	276	5			20	6.0	
201	197	2	316	4	1	16	32	9.9	2
202	88	0	220	2			33	4.8	
203	228	3	96	1	1	9	41	16.4	13
204	344	4	316	4			28	10.2	
205	234	2	328	4			29	7.2	
206	290	4	276	3			36	8.4	
207	220	5	280	4	1	8	28	13.3	5
208	138	2	248	4	1	13	33	8.4	4
209	305	6	96	1	2	19	35	29.6	23
210	443	6	324	6	1	14	25	9.9	1
211	345	6	476	7			21	14.7	
212	441	5	328	7	1	13	30	13.8	5
213	198	4	508	6			30	9.1	
214	371	5	324	4	2	8	33	13.6	6
215	171	20	356	5	2	16	27	14.6	5
216	389	8	276	23	3	24	23	37.9	27
217	397	19	432	10	3	19	29	15.6	7
218	291	5	488	20	2	19	27	19.4	10
219	329	4	220	4			21	10.1	
220	178	6	452	6			23	9.1	
221	273	6	168	3			18	4.2	
222	364	8	264	8			19	3.9	
223	152	3	356	6			21	12.9	
224	501	8	464	10	1	19	25	12.3	2
225	342	9	612	9			22	12.4	
226	467	7	328	9	2	22	25	17.4	7
227	320	9	660	11			21	14.6	
228	219	11	204	4			20	3.8	
229	165	2	200	12			17	11.7	
230	179	3	176	3			24	8.1	
231	185	4	176	3			25	10.9	
232	112	9	168	3			24	11.4	
233	321	6	8	1			0	554.5	
234	265	6	344	8			19	10.7	
235	320	9	292	5			21	3.6	

Figure C-13. UTCS System Performance Report (Sheet 5 of 6)

OUT OF TOLERANCE LINK NUMBER	HISTORY VOL (VEH)	HISTORY OCC (PCT)	CURRENT CUMULATIVE MOE VOL (VPH)	OCC (PCT)	QUEUE (VEH/CYCLE)	STOPS (NO.)	AV.SP. (MPH)	TRAV.TIME (SEC/VEH)	DELAY (SEC/VEH)
236	265	6	164	15	3	26	20	53.4	41
237	291	4	388	8	2	19	23	13.2	2
238	230	7	424	5			26	7.8	
239	596	34	204	10	1	8	22	10.4	4
240	121	2	0	0	0	0	0	.0	0
241	449	9	196	4	1	15	31	9.7	5
242	124	3	432	11			18	9.7	
243	449	9	136	2			22	13.8	
244	384	10	308	4			24	8.4	
245	190	3	432	9			20	8.6	
246	235	21	312	11	3	48	26	27.6	18
247	420	11	372	11	3	36	22	22.7	12
248	53	4	500	11	2	19	22	8.9	2
249	347	8	168	6	2	19	16	18.3	9
250	576	28	380	13	1	21	19	9.6	2
251	320	9	772	26			22	7.1	
252	19	1	312	8	1	20	22	14.3	3
253	57	10	28	8	2	18	15	141.2	125
254	395	6	204	7			19	14.5	
255	1	0	500	8			22	11.2	
256*	0	0	336	7	0	0	20	13.8	0
257*	0	0	404	8	0	0	23	5.9	0
258*	0	0	288	3	0	0	32	11.6	0
259*	0	0	360	3	0	0	35	10.6	0
260*	0	0	392	5	0	0	25	14.8	0
261*	0	0	364	4	0	0	28	10.9	0
262*	0	0	324	4	0	0	29	9.4	0
263*	0	0	680	9	0	0	25	10.8	0
264*	0	0	624	19	0	0	21	3.2	0
265*	0	0	328	5	0	0	24	15.4	0

Figure C-13. UTCS System Performance Report (Sheet 6 of 6)

BPS SYSTEM STATUS

SECTION	BPS	INTERSECTIONS PRE-EMPT	INHIBIT	FAILURES
1	0	0	1	0
2	2	0	2	1
3	13	0	6	0
4	5	0	1	0

BPS 15-MINUTE SECTION SUMMARY

SECTION	ELIGIBLE BUSES STOP	ELIGIBLE BUSES THRU	EXTENSIONS GRANTED	HELPED BUSES STOP	HELPED BUSES THRU	PSG.MIN. SAVED
1	0	0	0	0	0	0
2	2	2	7	0	5	50
3	4	28	22	2	13	104
4	0	7	2	0	0	0
SYSTEM TOTALS	6	37	31	2	18	154

Figure C-14. BPS System Status and 15-Minute Section Summary

C. 2. 8 BPS 15-Minute Section Summary

This report (Figure C-14) presents a 15-Minute summary of Eligible and Helped buses (Stop and Thru), the number of extensions granted, and the passenger-minutes saved for each section.

C. 2. 9 BPS 15-Minute Zone Summary

The BPS 15-Minute Zone Summary (Figure C-15) presents the 15-minute performance summaries for all BPS zones. Zones are referenced to its associated intersection and section. The direction of each zone is also given for ready reference. The 15-minute mode of operation indicates the operational status of the zone just before the 15-minute mark. Operational status codes include Release (REL), Inhibit (INH), Activate (ACT), Preempt (PRE), and Failed (FAIL).

Figure C-15 indicates that not all of the BPS zones were activated for BPS operation. This is indicated in the 15-Minute Mode of Operation column. The printout was obtained during system tests when only limited BPS operation was in effect.

C. 3 End of Day Report

The End of Day Report provides a summary of both the UTCS and BPS operation and performance. The report is printed out automatically whenever the traffic system is shut down via the control panel.

C. 3. 1 UTCS End of Day Report

The UTCS End of Day Report (Figure C-16) presents the sum total or average value of the MOE parameters for each link. The links are grouped according to their associated sections. The parameters are also totaled for each section and finally for the entire system. Note that an "NI" (not instrumented) is listed in the Delay, Stops, and Queue columns for those links which are not multi-detector links.

The significance of the MOE parameters presented in the UTCS End of Day Report are summarized as follows:

Delay - The total delay in hours experienced by all vehicles on a link, a section, or in the entire system over the period during a day that the traffic system is on-line.

BPS 15-MINUTE ZONE SUMMARY

SECT	INTSCT	ZONE	DIR	15-MIN. MODE OF OPER.	STOP BUS VOL.	THRU BUS VOL.	ELIGIBLE STOP BUSES	ELIGIBLE THRU BUSES	EXTNS GRANTED	HELPED STOP BUSES	HELPED THRU BUSES	PSG. MIN. SAVED
1	17	5	W	INH	1	1	0	0	0	0	0	0
		6	E	INH	0	0	0	0	0	0	0	0
		7	S	INH	2	1	0	0	0	0	0	0
2	10	1	N	ACT	1	2	0	1	1	0	2	46
		2	S	ACT	1	0	0	0	0	0	0	0
	12	3	N	INH	0	1	0	0	0	0	0	0
		4	S	INH	0	1	0	0	0	0	0	0
	120	67	N	INH	2	4	1	1	2	0	1	0
		68	S	INH	1	3	0	0	2	0	1	0
	121	69	N	FAIL	0	0	0	0	0	0	0	0
		70	S	REL	0	0	0	0	0	0	0	0
	123	71	N	ACT	3	0	1	0	1	0	1	4
		72	S	ACT	0	0	0	0	1	0	0	0
3	54	15	NW	ACT	2	1	1	0	1	0	0	0
		16	N	ACT	0	2	0	0	0	0	0	0
		17	SE	ACT	2	1	2	1	3	2	0	0
	55	18	W	ACT	1	1	0	1	0	0	0	0
		19	SE	ACT	0	0	0	0	0	0	0	0
	59	22	W	ACT	0	5	0	2	0	0	0	0
		23	E	ACT	1	4	0	0	0	0	0	0
		24	S	ACT	1	3	0	0	0	0	0	0
	60	25	W	INH	0	3	0	0	0	0	0	0
		26	N	INH	0	0	0	0	0	0	0	0
		27	E	INH	7	0	0	0	0	0	0	0
	66	30	NW	ACT	2	1	0	1	1	0	0	0
		31	SE	ACT	3	1	0	0	0	0	0	0
	68	32	W	ACT	0	0	0	0	0	0	0	0
		33	S	ACT	1	0	0	0	0	0	0	0
	70	34	NW	INH	1	0	0	0	0	0	0	0
		35	SE	INH	0	2	0	0	0	0	0	0
		36	S	INH	0	0	0	0	0	0	0	0
	72	37	W	ACT	0	0	0	0	0	0	0	0
		38	E	ACT	0	0	0	0	0	0	0	0
		39	S	ACT	0	3	0	0	0	0	0	0
	73	40	W	ACT	0	4	0	0	3	0	4	0
		41	N	ACT	0	0	0	0	0	0	0	0
		42	E	ACT	1	4	1	3	3	0	3	65
	76	43	S	ACT	0	3	0	1	1	0	0	0
	77	44	N	ACT	0	8	0	4	3	0	6	39
	82	45	N	INH	0	2	0	0	0	0	0	0
		46	S	INH	0	2	0	0	0	0	0	0
	84	47	S	ACT	1	3	0	0	0	0	0	0
	85	48	N	ACT	0	2	0	0	0	0	0	0
	88	49	W	INH	0	3	0	0	2	0	0	0

Figure C-15. BPS 15-Minute Zone Summary (Sheet 1 of 2)

SECT	INTSCT	ZONE	DIR	15-MIN. MODE OF OPER.	STOP BUS VOL.	THRU BUS VOL.	ELIGIBLE STOP BUSES	ELIGIBLE THRU BUSES	EXTNS GRANTED	HELPED STOP BUSES	HELPED THRU BUSES	PSG. MIN. SAVED
		50	N	INH	0	3	0	0	0	0	0	0
		51	E	INH	2	6	0	2	2	0	0	0
		52	S	INH	0	2	0	0	0	0	0	0
	91	53	N	INH	0	3	0	0	0	0	0	0
		54	S	INH	0	2	0	0	0	0	0	0
	93	55	W	ACT	0	8	0	5	3	0	0	0
		56	N	ACT	1	3	0	1	0	0	0	0
		57	S	ACT	0	0	0	0	0	0	0	0
	94	58	W	ACT	0	10	0	7	0	0	0	0
	97	59	N	INH	1	1	0	0	0	0	0	0
		60	S	INH	0	0	0	0	0	0	0	0
	99	61	W	INH	0	1	0	0	0	0	0	0
		62	N	INH	1	2	0	0	0	0	0	0
		63	E	INH	3	5	0	0	0	0	0	0
		64	S	INH	0	2	0	0	0	0	0	0
4	40	8	W	ACT	0	0	0	0	0	0	0	0
		9	E	ACT	0	0	0	0	0	0	0	0
	42	10	W	ACT	0	1	0	0	0	0	0	0
		11	E	ACT	0	0	0	0	0	0	0	0
	45	12	W	ACT	0	8	0	6	1	0	0	0
		13	S	ACT	0	0	0	0	0	0	0	0
	49	14	N	ACT	0	2	0	0	0	0	0	0
	57	20	W	ACT	0	0	0	0	0	0	0	0
		21	N	ACT	0	2	0	1	1	0	0	0
	115	65	N	INH	0	2	0	0	0	0	0	0
		66	E	INH	0	0	0	0	0	0	0	0

Figure C-15. BPS 15-Minute Zone Summary (Sheet 2 of 2)

END OF DAY REPORT

DATE DEC 07 72 TIME 1532

INITIAL TIME 1430 REPORT NO 1

	LINK	VOLUME VEHICLES	TRAV.TIME VEH-HRS	DELAY HRS	STOPS VEH	OCCUPANCY PERCENT	QUEUE VEH/CYCLE	SPEED MPH
SECTION 1	1	636	1.5	NI	NI	6.5	NI	17.9
	2	348	1.0	.0	62	6.0	1.3	21.2
	3	400	5.8	4.0	257	30.5	4.3	13.3
	4	428	1.3	NI	NI	4.5	NI	16.3
	5	168	1.3	1.0	129	8.5	1.8	16.3
	6	251	1.5	NI	NI	12.5	NI	11.1
	7	369	3.8	2.0	150	16.5	3.8	12.8
	8	245	3.3	2.5	164	15.8	2.8	12.1
	9	15	.0	NI	NI	2.5	NI	13.7
	10	463	5.3	3.0	176	15.5	5.3	13.6
	11	298	5.8	4.0	217	17.8	5.2	10.8
	12	493	2.3	NI	NI	6.5	NI	17.2
	13	457	1.8	NI	NI	6.0	NI	16.9
	15	496	1.3	NI	NI	5.3	NI	18.0
	16	291	1.5	NI	NI	5.8	NI	14.5
	17	155	.0	NI	NI	1.8	NI	16.2
	18	275	.5	NI	NI	2.5	NI	20.5
TOTAL		5788	37.5	16.5	1155			
AVERAGE			2.2	2.3	165	9.5	3.5	15.4
SECTION 2	19	541	2.3	NI	NI	5.5	NI	20.1
	20	397	2.0	1.0	97	6.0	2.0	23.3
	21	499	1.0	.0	66	5.3	1.1	18.9
	22	137	.5	NI	NI	1.5	NI	13.9
	23	21	.0	NI	NI	.3	NI	26.3
	24	465	3.3	1.5	136	8.5	3.1	20.0
	25	539	4.5	2.5	125	10.3	3.6	17.6
	26	135	.8	.5	62	6.8	1.0	16.4
	27	547	4.5	2.5	150	12.5	3.9	16.3
	28	96	2.0	2.0	140	3.3	2.2	19.8
	29	51	.0	NI	NI	.3	NI	19.8
	30	301	1.8	1.0	96	10.5	1.6	15.8
	31	119	1.3	1.0	95	2.5	1.4	17.7
	32	391	.8	.0	62	3.3	1.3	25.5
	33	251	1.5	1.0	116	3.5	1.7	16.1
	34	255	1.0	.5	89	3.3	1.7	21.8
	35	204	2.0	1.5	143	11.3	2.2	16.0
	36	410	1.5	.5	136	13.3	2.3	15.1
	37	138	1.3	1.0	107	10.8	1.8	12.3
	38	426	2.5	1.5	248	8.3	3.6	16.8
	39	153	1.3	1.0	117	7.0	1.8	17.1
	40	690	2.8	1.0	259	19.0	3.7	14.5
	41	206	2.5	2.0	142	6.8	2.1	12.8

Figure C-16. UTCS End of Day Report (Sheet 1 of 8)

DATE DEC 07 7? TIME 1532

INITIAL TIME 1430 REPORT NO 1

	LINK	VOLUME VEHICLES	TRAV.TIME VEH-HRS	DELAY HRS	STOPS VEH	OCCUPANCY PERCENT	QUEUE VEH/CYCLE	SPEED MPH
	42	521	1.8	.5	157	14.3	2.5	15.5
	43	221	1.0	.5	76	9.8	1.2	15.8
	44	629	2.3	1.0	169	9.8	2.3	19.1
	45	229	2.0	1.5	130	11.0	1.9	16.3
	46	438	3.0	2.0	221	12.3	3.3	16.4
	47	680	2.0	.5	206	9.8	3.4	17.2
	48	112	1.8	1.5	103	6.0	1.7	13.0
	49	486	.8	.0	128	5.5	1.8	21.4
TOTAL		10288	55.3	29.5	3576			
AVERAGE			1.8	1.1	132	7.5	2.2	17.7
SECTION 3	50	206	.5	NI	NI	2.3	NI	21.5
	51	162	.0	NI	NI	2.3	NI	13.8
	52	311	1.3	NI	NI	3.0	NI	19.5
	53	257	1.0	NI	NI	2.5	NI	19.7
	54	277	1.3	NI	NI	10.3	NI	14.9
	55	81	.0	NI	NI	.5	NI	22.5
	56	374	1.3	NI	NI	4.8	NI	16.9
	57	149	.5	NI	NI	3.0	NI	16.2
	58	376	.5	NI	NI	6.0	NI	18.1
	59	228	.0	NI	NI	3.5	NI	16.1
	60	216	.5	NI	NI	9.5	NI	13.8
	61	125	.5	NI	NI	5.5	NI	12.3
	62	413	3.5	2.0	162	7.8	2.7	19.2
	63	453	3.5	2.0	130	10.3	2.3	17.3
	64	132	.3	NI	NI	3.8	NI	13.6
	65	469	2.0	.5	87	7.3	1.7	19.0
	66	271	1.0	.5	82	4.0	1.6	19.9
	67	363	3.5	2.0	146	13.5	3.2	15.5
	68	556	6.5	3.5	158	16.3	4.3	12.5
	69	437	2.0	.5	64	7.3	1.3	17.3
	70	198	.5	NI	NI	4.5	NI	18.7
	71	22	.0	NI	NI	9.9	NI	13.3
	72	465	3.0	1.0	124	11.5	2.2	14.7
	73	258	.5	.0	74	6.5	1.1	20.3
	74	453	4.0	2.5	132	18.0	3.2	15.3
	75	475	3.0	1.5	202	8.8	3.5	20.3
	77	300	2.8	1.5	207	10.3	3.3	16.4
	78	509	1.0	NI	NI	21.3	NI	11.3
	79	272	1.5	.5	71	11.5	1.4	13.7
	80	345	2.3	1.0	161	8.8	2.0	18.9
	81	485	1.5	NI	NI	6.8	NI	15.8
	82	409	2.5	1.0	150	11.5	3.0	15.2

Figure C-16. UTCS End of Day Report (Sheet 2 of 8)

END OF DAY REPORT

DATE DEC 07 72 TIME 1532

INITIAL TIME 1430 REPORT NO 1

LINK	VOLUME VEHICLES	TRAV.TIME VEH-HRS	DELAY HRS	STOPS VEH	OCCUPANCY PERCENT	QUEUE VEH/CYCLE	SPEED MPH
83	196	.8	NI	NI	3.3	NI	13.6
85	275	.8	NI	NI	3.0	NI	15.8
86	281	2.0	NI	NI	13.3	NI	9.9
87	208	.8	NI	NI	4.0	NI	13.6
88	376	.8	.0	83	8.5	1.0	18.2
89	467	4.5	2.5	138	11.8	3.0	15.3
90	341	1.3	.5	85	7.5	1.2	15.8
91	270	1.0	NI	NI	3.0	NI	19.0
92	418	.5	NI	NI	11.5	NI	12.8
93	423	2.0	.5	137	12.3	1.8	15.6
95	180	1.0	.5	63	6.5	1.7	16.9
96	274	1.3	NI	NI	10.0	NI	14.5
98	481	4.0	2.0	176	10.3	5.3	15.5
99	379	2.0	1.0	152	16.3	2.8	14.8
100	59	.3	NI	NI	.8	NI	10.9
102	49	.3	NI	NI	1.0	NI	8.3
104	440	4.3	2.5	228	12.3	5.7	17.8
105	327	1.5	1.0	113	8.8	1.9	18.4
106	313	2.0	NI	NI	14.5	NI	10.8
107	494	.8	NI	NI	7.5	NI	17.2
108	449	1.8	.5	72	7.8	1.6	23.3
109	288	.8	.0	55	4.0	1.3	25.1
110	439	4.5	3.0	145	17.0	3.5	16.6
111	444	.8	.0	70	7.8	1.1	20.1
112	342	2.0	1.0	85	7.3	1.5	17.1
113	239	.5	NI	NI	2.5	NI	19.4
114	281	2.0	1.0	132	8.0	2.4	19.4
116	440	1.0	NI	NI	6.5	NI	19.6
117	549	2.8	NI	NI	13.8	NI	16.9
118	108	.3	NI	NI	.8	NI	22.8
119	300	1.0	NI	NI	2.8	NI	20.5
120	344	1.5	NI	NI	13.0	NI	11.5
121	141	.3	NI	NI	1.5	NI	17.9
122	338	.5	NI	NI	4.8	NI	16.4
123	509	2.0	NI	NI	7.8	NI	16.3
124	264	2.8	2.0	161	5.5	2.8	19.6
125	722	4.3	1.0	133	14.5	4.1	15.3
126	494	1.8	NI	NI	8.8	NI	15.3
127	493	3.8	1.5	171	14.8	3.0	12.5
128	419	1.5	NI	NI	6.3	NI	16.0
129	322	2.3	1.0	97	10.8	2.1	15.7
130	564	3.0	NI	NI	9.0	NI	14.1
131	187	.5	NI	NI	3.8	NI	16.5
132	534	3.0	NI	NI	7.8	NI	12.8
133	277	1.8	NI	NI	5.0	NI	12.5

Figure C-16. UTCS End of Day Report (Sheet 3 of 8)

DATE DEC 07 72 TIME 1532

INITIAL TIME 1430 REPORT NO 1

LINK	VOLUME VEHICLES	TRAV.TIME VEH-HRS	DELAY HRS	STOPS VEH	OCCUPANCY PERCENT	QUEUE VEH/CYCLE	SPEED MPH
134	600	2.5	NI	NI	7.5	NI	16.3
135	271	1.8	1.0	117	4.8	2.3	18.1
136	199	.5	NI	NI	1.5	NI	23.9
137	492	22.3	20.0	171	13.8	3.5	14.1
138	271	2.0	1.0	72	6.8	2.2	16.5
139	412	2.0	NI	NI	7.8	NI	15.7
140	444	1.5	NI	NI	8.0	NI	15.3
141	336	1.3	NI	NI	6.3	NI	14.9
142	517	1.8	NI	NI	6.0	NI	16.6
143	607	3.3	NI	NI	9.5	NI	14.4
144	126	.5	NI	NI	6.8	NI	15.1
145	533	1.8	NI	NI	8.0	NI	17.6
146	454	3.3	1.5	140	11.0	3.1	14.6
147	614	4.3	1.0	93	13.5	2.6	12.8
148	580	3.0	NI	NI	26.8	NI	10.5
149	393	3.8	2.5	214	7.3	4.1	16.8
150	248	.8	NI	NI	2.5	NI	18.3
151	435	3.0	1.0	91	11.8	2.2	15.0
152	578	2.5	NI	NI	8.8	NI	12.5
153	532	5.0	2.0	215	21.0	3.2	11.7
154	461	3.5	1.5	220	15.0	3.1	14.5
155	48	.0	NI	NI	.8	NI	.0
156	350	.8	NI	NI	8.3	NI	13.7
157	237	2.3	1.5	113	11.8	3.0	14.6
158	432	2.5	1.0	131	12.8	2.7	18.0
159	278	4.8	3.5	217	19.0	4.3	9.6
160	395	2.5	1.0	99	9.5	2.4	16.1
161	296	2.5	1.5	136	11.8	2.9	13.9
162	436	.5	NI	NI	6.0	NI	16.6
163	295	2.3	1.5	104	9.8	2.2	17.5
164	330	1.5	.5	117	7.0	2.2	22.3
165	158	.5	NI	NI	9.8	NI	16.8
166	241	1.0	NI	NI	3.0	NI	15.4
167	217	1.0	NI	NI	4.5	NI	11.4
168	169	2.0	.5	1	16.8	.7	6.3
169	398	1.5	NI	NI	13.5	NI	13.4
170	181	4.0	3.5	242	15.8	3.2	13.4
171	304	1.3	.5	109	5.0	1.5	16.2
172	489	1.0	NI	NI	7.5	NI	15.9
173	135	2.3	1.5	167	6.3	3.4	11.8
174	301	2.3	1.0	83	8.0	2.1	13.4
175	394	1.8	1.0	176	9.5	2.4	15.7
177	394	3.0	1.5	123	9.8	3.5	13.6
178	472	1.0	NI	NI	13.3	NI	14.3
179	313	1.3	NI	NI	4.0	NI	15.9

Figure C-16. UTCS End of Day Report (Sheet 4 of 8)

END OF DAY REPORT

DATE DEC 07 72 TIME 1532

INITIAL TIME 1430 REPORT NO 1

	LINK	VOLUME VEHICLES	TRAV.TIME VEH-HRS	DELAY HRS	STOPS VEH	OCCUPANCY PERCENT	QUEUE VEH/CYCLE	SPEED MPH
	180	490	1.5	NI	NI	6.5	NI	16.1
	181	463	1.3	NI	NI	4.5	NI	25.4
	183	453	2.5	1.0	0	10.5	2.3	16.8
	184	448	1.8	.5	67	18.3	1.1	13.8
	185	275	2.3	1.0	0	11.0	2.1	15.6
	186	356	1.5	.5	75	9.0	1.4	20.0
	187	461	2.0	.5	114	11.5	1.1	14.2
	188	247	1.3	NI	NI	21.0	NI	11.1
	189	280	.8	.0	56	5.3	.9	19.2
	190	372	3.3	2.0	142	15.8	2.6	13.8
	191	434	3.0	1.5	133	12.3	3.3	17.6
	192	330	2.3	1.0	88	15.8	2.1	13.3
	193	471	1.0	NI	NI	6.3	NI	16.2
	194	362	3.0	2.0	166	8.8	3.3	18.1
TOTAL		47593	270.0	103.0	8238			
AVERAGE			2.0	1.5	122	8.5	2.5	15.9
SECTION 4	195	283	1.0	.5	98	3.3	1.1	20.3
	196	46	.0	NI	NI	.8	NI	13.2
	197	126	1.0	.0	13	3.5	.3	7.3
	198	241	1.5	1.0	106	6.0	1.6	25.9
	199	373	2.0	1.0	95	6.3	2.0	25.5
	200	302	.5	NI	NI	3.5	NI	16.6
	201	360	.8	.0	71	2.8	1.2	25.7
	202	195	.3	NI	NI	1.3	NI	25.8
	203	60	2.0	2.0	124	.3	1.8	25.4
	204	239	.8	NI	NI	1.8	NI	22.3
	205	387	.8	NI	NI	2.8	NI	23.4
	206	238	.5	NI	NI	1.5	NI	28.9
	207	322	.8	.0	46	2.8	.8	23.2
	208	229	1.3	1.0	132	2.0	1.8	27.4
	209	111	.8	.5	65	.8	1.4	26.8
	210	287	.8	.0	70	3.5	1.1	21.3
	211	467	2.3	NI	NI	4.8	NI	17.5
	212	389	1.5	.5	80	5.8	1.3	24.1
	213	470	1.3	NI	NI	3.5	NI	25.2
	214	255	1.0	.5	53	2.5	1.7	26.0
	215	384	1.8	.5	95	4.3	1.3	21.4
	216	279	2.8	2.0	117	13.3	2.3	19.3
	217	398	1.5	.5	84	6.0	1.9	24.8
	218	471	2.8	1.5	98	12.3	1.8	22.0
	219	248	.5	NI	NI	2.5	NI	21.0
	220	386	1.0	NI	NI	3.5	NI	19.9

Figure C-16. UTCS End of Day Report (Sheet 5 of 8)

DATE DEC 07 72 TIME 1532

INITIAL TIME 1430 REPORT NO 1

	LINK	VOLUME VEHICLES	TRAV.TIME VEH-HRS	DELAY HRS	STOPS VEH	OCCUPANCY PERCENT	QUEUE VEH/CYCLE	SPEED MPH
	221	149	.0	NI	NI	3.0	NI	14.3
	222	271	.3	NI	NI	5.8	NI	13.8
	223	397	1.8	NI	NI	9.3	NI	15.9
	224	430	1.5	.0	88	5.8	1.4	19.6
	225	557	2.0	NI	NI	5.8	NI	18.9
	226	332	1.5	.5	86	6.3	1.6	21.2
	227	515	2.0	NI	NI	5.0	NI	20.7
	228	202	.3	NI	NI	3.0	NI	12.7
	229	179	.5	NI	NI	6.8	NI	12.9
	230	155	.3	NI	NI	1.5	NI	17.9
	231	173	.5	NI	NI	1.8	NI	21.5
	232	193	.5	NI	NI	2.0	NI	20.1
	233	43	.3	NI	NI	3.3	NI	8.8
	234	308	1.0	NI	NI	3.5	NI	16.7
	235	303	.3	NI	NI	4.0	NI	16.1
	236	148	1.5	1.0	102	8.0	1.9	18.1
	237	340	1.5	.5	86	4.8	1.4	19.4
	238	393	1.0	NI	NI	3.8	NI	20.3
	239	239	.3	.0	73	7.3	1.0	19.1
	240	31	.0	.0	21	.5	.6	13.1
	241	166	.8	.5	105	2.3	1.7	23.8
	242	464	1.3	NI	NI	5.8	NI	17.3
	243	107	.5	NI	NI	2.0	NI	14.5
	244	334	.8	NI	NI	3.3	NI	20.9
	245	433	1.3	NI	NI	6.3	NI	15.9
	246	293	2.8	2.0	230	7.0	2.8	21.3
	247	314	2.5	1.5	202	5.8	2.4	20.5
	248	479	1.0	.0	106	6.8	1.4	18.7
	249	194	3.0	2.5	215	5.5	3.3	12.7
	250	398	1.0	.0	110	7.5	1.4	15.6
	251	710	1.5	NI	NI	15.5	NI	19.1
	252	324	1.8	.5	127	5.8	1.7	17.4
	253	28	1.5	1.5	118	1.8	2.4	17.1
	254	125	.5	NI	NI	11.8	NI	15.6
	255	418	1.5	NI	NI	4.5	NI	17.6
TOTAL		17681	69.0	22.0	3016			
AVERAGE			1.1	.7	100	4.5	1.6	19.5
SECTION 5	256	368	1.5	NI	NI	5.5	NI	16.6
	257	363	.8	NI	NI	6.8	NI	16.5
	258	309	1.3	NI	NI	2.0	NI	24.8
	259	309	1.0	NI	NI	2.0	NI	26.4
	260	358	1.8	NI	NI	3.3	NI	18.9

Figure C-16. UTCS End of Day Report (Sheet 6 of 8)

END OF DAY REPORT

DATE DEC 07 72 TIME 1532

INITIAL TIME 1430 REPORT NO 1

LINK	VOLUME VEHICLES	TRAV.TIME VEH-HRS	DELAY HRS	STOPS VEH	OCCUPANCY PERCENT	QUEUE VEH/CYCLE	SPEED MPH
261	330	1.3	NI	NI	2.8	NI	20.6
262	318	1.0	NI	NI	2.5	NI	22.2
263	625	2.3	NI	NI	5.3	NI	20.3
264	588	.5	NI	NI	9.0	NI	17.1
265	295	1.5	NI	NI	3.5	NI	18.3
266	0	.0	NI	NI	.0	NI	.0
267	0	.0	NI	NI	.0	NI	.0
269	0	.0	NI	NI	.0	NI	.0
270	0	.0	NI	NI	.0	NI	.0
TOTAL	3863	12.8	.0	0			
AVERAGE		.9	.0	0	3.0	.0	14.4

Figure C-16. UTCS End of Day Report (Sheet 7 of 8)

SYSTEM PERFORMANCE	VOLUME TOTAL	TRAV.TIME TOTAL	DELAY TOTAL	STOPS TOTAL	OCCUPANCY PERCENT	QUEUE AVERAGE	SPEED AVERAGE
	85213	444.5	171.0	15985	7.3	2.3	16.9

Figure C-16. UTCS End of Day Report (Sheet 8 of 8)

Occupancy - The average percent occupancy of all the 15-minute accumulations of raw occupancy for a link, a section, or the entire system over the period during a day that the traffic system is on-line.

Queue - The average of the queues in vehicles per cycle for all cycles for a link, a section or the entire system over the period during a day that the traffic system is on-line.

Speed - The average speed in miles per hour of all the 15-minute accumulations of raw speed for a link, a section, or the entire system over the period during a day that the traffic system is on-line.

Stops - the total number of stopped vehicles for a link, a section, or the system over the period during a day that the traffic system is on-line.

Travel Time - The total time in hours that is spent by all vehicles in a link, in the links which comprise a section, or in all links of the total system over the period during a day that the traffic system is on-line.

Volume - The total number of vehicles passing through a link, the links which comprise a section, or in all of the links of the total system over the period during a day that the traffic system is on-line.

C.3.2 BPS End of Day Section Summary

The BPS End of Day Section Summary (Figure C-17) presents the sum total of BPS performance parameters for all the 15-minute periods that the traffic system is on-line during the operating day. The report heading format is identical to that used in the BPS 15-Minute Section Summary (Figure C-14).

C.3.3 BPS End of Day Zone Summary

The BPS End of Day Zone Summary (Figure C-18) presents the sum total of BPS performance parameters for all the 15-minute periods that the traffic system is on-line during the operating day. The report headings for these parameters are identical to those used in the BPS 15-Minute Zone Summary (Figure C-15). However, the Intersection and Direction headings are not used in the End of Day Summary. In their place is a breakdown of the number of 15-minute periods during which the zone operated in a failed, released, activated, preempted, or inhibited condition.

BPS END OF DAY SECTION SUMMARY

SECTION	ELIGIBLE BUSES STOP	ELIGIBLE BUSES THRU	EXTENSIONS GRANTED	HELPED BUSES STOP	HELPED BUSES THRU	PSG.MIN. SAVED
1	0	4	6	0	0	0
2	4	15	46	1	9	61
3	6	62	79	0	65	179
4	0	15	10	0	3	0
SYSTEM TOTALS	10	96	141	1	77	240

Figure C-17. BPS End of Day Section Summary

SECT	ZONE	15-MIN. MODE OF OPERATION FAIL	REL	ACT	PRE	INH	STOP BUS VOL.	THRU BUS VOL.	ELIGIBLE STOP BUSES	ELIGIBLE THRU BUSES	EXTNS GRANTED	HELPED STOP BUSES	HELPED THRU BUSES	PSG. MIN. SAVED
1	5	0	1	0	0	4	1	9	0	4	3	0	0	0
	6	0	1	0	0	4	0	0	0	0	3	0	0	0
	7	0	1	0	0	4	0	5	0	0	0	0	0	0
2	1	0	1	1	0	3	1	9	0	0	0	0	0	0
	2	0	1	1	0	3	0	13	0	0	0	0	0	0
	3	0	1	2	0	2	0	7	0	1	2	0	0	0
	4	0	1	2	0	2	0	5	0	1	2	0	0	0
	67	0	1	0	0	4	2	9	0	1	5	0	1	13
	68	0	1	0	0	4	0	15	0	3	5	0	2	17
	69	5	0	0	0	0	0	0	0	0	0	0	0	0
	70	0	5	0	0	0	0	0	0	0	0	0	0	0
	71	0	1	2	0	2	5	6	4	2	16	1	1	8
	72	0	1	2	0	2	0	10	0	7	16	0	5	23
3	15	0	1	2	0	2	1	13	1	4	6	0	7	0
	16	0	1	2	0	2	1	7	0	3	3	0	3	0
	17	0	1	2	0	2	0	6	0	0	0	0	0	0
	18	0	4	1	0	0	1	8	0	1	1	0	2	35
	19	1	3	1	0	0	0	0	0	0	1	0	1	0
	22	0	1	2	0	2	2	11	0	0	0	0	0	0
	23	0	1	2	0	2	2	11	0	0	0	0	0	0
	24	0	1	2	0	2	0	11	0	4	2	0	6	0
	25	0	1	0	0	4	2	13	0	0	0	0	0	0
	26	0	1	0	0	4	0	0	0	0	0	0	0	0
	27	0	1	0	0	4	22	0	0	0	0	0	0	0
	28	0	5	0	0	0	0	0	0	0	0	0	0	0
	29	0	5	0	0	0	0	0	0	0	0	0	0	0
	30	0	1	2	0	2	1	13	0	5	5	0	6	15
	31	0	1	2	0	2	0	9	0	1	1	0	1	0
	32	0	1	3	0	1	4	6	0	0	0	0	0	0
	33	0	1	3	0	1	1	0	0	0	0	0	0	0
	34	0	1	2	0	2	1	0	0	0	0	0	0	0
	35	0	1	2	0	2	0	6	0	2	2	0	0	0
	36	0	1	2	0	2	0	0	0	0	0	0	0	0
	37	0	3	2	0	0	0	0	0	0	0	0	0	0
	38	0	3	2	0	0	0	0	0	0	0	0	0	0
	39	0	3	2	0	0	1	7	0	4	4	0	8	0
	40	0	1	3	0	1	2	11	0	0	6	0	1	0
	41	0	1	3	0	1	0	0	0	0	0	0	0	0
	42	0	1	3	0	1	2	11	0	8	6	0	7	67
	43	2	1	0	0	2	1	7	0	1	7	0	0	0
	44	0	1	3	0	1	4	18	0	11	6	0	14	0
	45	0	1	2	0	2	3	3	0	0	1	0	0	0
	46	0	1	2	0	2	0	3	0	1	1	0	0	0
	47	0	1	0	0	4	0	10	0	2	3	0	0	0

Figure C-18. BPS End of Day Zone Summary (Sheet 1 of 2)

SECT	ZONE	15-MIN. MODE OF OPERATION FAIL	REL	ACT	PRE	INH	STOP BUS VAL.	THRU BUS VAL.	ELIGIBLE STOP BUSES	ELIGIBLE THRU BUSES	EXTNS GRANTED	HELPED STOP BUSES	HELPED THRU BUSES	PSG. MIN. SAVED
	48	0	1	3	0	1	0	7	0	3	3	0	1	32
	49	0	1	0	0	4	2	12	0	0	2	0	0	0
	50	0	1	0	0	4	3	3	0	0	0	0	0	0
	51	0	1	0	0	4	3	20	2	1	2	0	1	30
	52	0	1	0	0	4	0	6	0	0	0	0	0	0
	53	0	1	0	0	4	1	5	0	0	0	0	0	0
	54	0	1	0	0	4	0	3	0	0	0	0	0	0
	55	0	1	2	0	2	3	15	2	6	7	0	0	0
	56	0	1	2	0	2	0	7	0	0	0	0	0	0
	57	0	1	2	0	2	0	0	0	0	0	0	0	0
	58	5	0	0	0	0	0	0	0	0	0	0	0	0
	59	0	1	3	0	1	1	1	0	0	0	0	0	0
	60	0	1	3	0	1	0	0	0	0	0	0	0	0
	61	0	1	2	0	2	2	12	1	3	5	0	4	0
	62	0	1	2	0	2	1	1	0	0	0	0	0	0
	63	0	1	2	0	2	2	18	0	2	5	0	3	0
	64	0	1	2	0	2	0	2	0	0	0	0	0	0
4	8	0	1	2	0	2	0	0	0	0	0	0	0	0
	9	0	1	2	0	2	0	0	0	0	0	0	0	0
	10	0	1	3	0	1	0	1	0	0	0	0	0	0
	11	0	1	3	0	1	0	0	0	0	0	0	0	0
	12	0	1	2	0	2	0	6	0	6	1	0	0	0
	13	0	1	2	0	2	0	6	0	5	3	0	0	0
	14	0	1	2	0	2	1	6	0	2	4	0	2	0
	20	0	1	2	0	2	0	1	0	0	0	0	0	0
	21	0	1	2	0	2	1	7	0	2	2	0	1	0
	65	0	1	1	0	3	1	7	0	0	0	0	0	0
	66	0	1	1	0	3	0	3	0	0	0	0	0	0

Figure C-18. BPS End of Day Zone Summary (Sheet 2 of 2)

EQUIPMENT INSTALLATION

and

CENTRAL SITE SPECIFICATION

UTCS/BPS PROGRAM

APPROVALS

NAME	DATE	POSITION
J. Whitefall	2/22/71	Sr. Engineer
R. Wittner	3/1/71	Engineering Dept. Head

LINE NO.

REVISION RECORD

DATE	REV.	PAGE	DESCRIPTION
12/28/70	A	15 (Figure 1)	Added six radio line cabinets in room behind map to layout.
1/18/71		2	Replace "in order to" with "to further" line 31. Changed "may" to "map" bottom of page and add date 23 October 1970.
1/18/71		3	Change Table I to Table II. Add "All power leads from the breaker to the recepticles shall be run under the raised floor in greenfield or conduit".
1/18/71		12	Added (2) under CIU in column 1 row 3. Changed 1000 to 600 ea and added 1200 total in column 3 row 3. Changed 111 to 65 lbs/sq. ft. and 250 to 150 lbs/caster in column 4 row 3.
1/18/71		14	Added 146 lbs. weight for CRT's in column 3 row 1 Added C.P.; changed Est. 13,600 to 2400 BTU/HR and 13,941 total to 2741 total in column 5 row 1 Changed 2 KVA ea (CRT) to 0.7 KVA (CRT-2) and 4.1 KVA total to 0.8 KVA total and removed 2 connectors 3120 in column 7 row 1.
1/18/71		Figure 1	Removed two communications/termination cabinets and increased the single Accessory cabinet to two Accessor cabinets.
2/18/71		4	Line 15 change optimum 72 degrees to optimum 70 degrees Line 21 change Optimum 50% to optimum 45% and replace (not to exceed a dew point temperature at 61 degrees) with (In no case should the relative humidity be kept at a level which allows condensation anywhere within the control center. Line 33 add "The filter shall remove 80% of the particles 0.3 microns or larger.
2/18/71		5	Line 13 and 14 change "Radio link monitoring provision will be provided later, if required" to "Radio link monitoring provisions shall be provided".
2/18/71		6	Line 24 change Qty 1 to 2 Line 28 change 16-18 Est to 10 Line 29 add Map electronics cabinet 1
		7	Line 14 add card storage cabinet 2½' x 1½' x 2½' 5 double drawer.

LINE NO.

DATE	REV.	PAGE	DESCRIPTION
2/18/71		12	Column 1 Row 3 add (2) Column 3 Row 3 change 1000 to 600 ea add 1200 total Column 4 Row 3 change 111 to 65 change 250 ; to 150
2/18/71		13	Column 3 Row 3 delete 80 lbs/jack pad Column 4 Row 3 add 78 lbs/sq ft
2/18/71		14	Column 3 Row 1 add CRT (2) 146 add Console TBA Column 5 Row 1 change 13,600 to 2400 change 13,941 to 2741 total Column 7 Row 1 change 2 KVA ea to 0.7 KVA change (CRT) to (CRT-2) change 4.1 KVA total to 0.8 KVA total delete 2 connectors 3120
2/18/71		15	Added two accessory CIU cabinets and corrected total cabinet count
2/18/71		16	Completely revised
2/18/71		17-22	Completely revised

LINE NO.

1. CENTRAL SITE SPECIFICATIONS

1.1 Room Layout

The layout of the Washington, D.C., UTCS Control Center equipment is provided in Figure 1.

1.2 Raised Floor

A raised floor similar to LISKY rigid steel grid with 2' x 2' removable panels or recessed sub floor "pit" shall be provided for this room for cable routing between equipments. The raised floor structure shall be capable of sustaining a uniform load of 250 PSF, or a concentrated load of 1,000 pounds, with a maximum deflection of 1/10 of an inch. The height from the sub-floor to the top of the finished floor shall be 10 inches minimum. The underfloor area shall serve as the supply air plenum. Floor panels shall hold securely at a pressure of 0.5 inches measured by a water guage. All joints at facia's and floor as well as where the elevated floor meets existing or planned partitions shall be sealed so as to assure the aforementioned air leakage requirements. All modular floor panels shall have a top faced surface of material suitable for use in a computer installation (i.e., shall be anti-static in nature to avoid damage to magnetic tapes).

1.3 Walls

The room shall be insulated to reduce the air conditioning load. The interior walls shall be covered by an acoustic material. The material recommended is acoustic tile, or heavy draperies the choice being optional. Glass partitions and doors shall be provided as indicated for the wall between the control room and anteroom. Thermopane shall be considered to further reduce the air conditioning load.

1.4 Structural Ceiling

The structural ceiling shall be watertight and dust-tight under all conditions including roof rework to eliminate damage to the equipments and the room.

1.5 Suspended Ceiling and Lighting

The suspended ceiling shall be no lower than 10 feet above the raised flooring, and shall be constructed of acoustical material for noise reduction. The ceiling may be used for a return air plenum for the air conditioning system. The ceiling shall also contain the lighting system which shall meet the following requirements:

- provide an overall intensity of 40 foot candles at a distance of 30 inches from the raised floor
- Provide switching and dimmer controls to permit extinguishing or dimming of lamps in front of the display map without affecting the other room lamps.

LINE NO.

1.6 Fire Protection

All material used in the construction and decoration of the room shall be non-combustible with a flame-spread rating of 25 or less. Smoke detectors shall be installed in the suspended ceiling and in the space between the raised floor and sub-floor. These smoke detectors shall produce an audible alarm but have no provision for disconnecting equipment power.

Additional fire protection shall be provided either by use of a sprinkler system or CO_2 system.

1.6.1 Sprinkler System

Sprinkler systems shall be equipped such that a minimum of 212 degrees F is required before tripping. An automatic power disconnect control device shall be incorporated into the sprinkler system to shut off all power to the equipments upon sprinkler discharge.

1.6.2 CO_2 System

The CO_2 system shall be a centralized type with nozzil discharge directly into electrical equipment. A personnel alarm shall be provided to alert the operators prior to the despensing of CO_2.

1.7 Electrical Power

Adequate 60 Hz power shall be supplied to the room. The power shall be provided through a separate transformer and must have no other heavy or intermettent load such as machine shop equipment, air conditioners, tabulating equipment and the like. The basic requirements for the 60 Hz input power shall be as follows:

- o Voltage: 120/208 volts
- o Voltage variation: +5%, - 10% from nominal
- o Frequency: 60 Hz $\pm$ 0.5 Hz
- o Phase: 3 phase wye
- o Connection: 5 wire (4 wire and ground)
- o Harmonic Distrotion: 3% maximum
- o Load capacity: 50 KVA

Convenience outlets providing 120 volt, 60 Hz, single phase service shall be provided around the perimeter of the room at 10 foot intervals. The height of these outlets above the raised floor shall not exceed two feet.

Each xerox equipment cabinet shall be supplied by an individual circuit breaker. The recommended breaker size is provided in Table II. All power leads from the breaker to the recepticles shall be run under the raised floor in green-

field. A description of the power receptables required for UTCS are provided in Figure 2.

1.8 Air Conditioning

The room shall have an adequate and reliable air conditioning system. The basic requirements for this system shall be as follows:

- o Temperature Requirements
  - minimum: 66 degrees F.
  - maximum: 76 degrees F.
  - optimum: 70 degrees F. + -3 degrees F.
  - gradient: 10 degrees F. per hour
- o Humidity Requirements
  - optimum: 45% + or _5% (In no case should the relative humidity be kept at a level which allows condensation anywhere within the control center.
- o Heat Dissipation
  - typical: 111,000 BTU/hour equipment
    3,300 personnel (6 people)
    26,500 lighting (Est.)
    145,800
- o Filtration
  - minimum efficiency rating: 80%

The filter shall remove 80% of the particles 0.3 microns or larger.

Once temperature stabilization is initially reached, the air conditioning system shall be capable of maintaining the temperature within + or - 4 degrees F. regardless of outside temperature extremes.

All air-conditioning ducts, if used, shall be properly wrapped to prevent condensation damage to installed equipments. Air-conditioning return registers shall be placed over or near the equipment exhaust outlets to facilitate the removal of hot exhaust air. In any instance, room air circulation shall be controlled to prevent "hot" or "cold" spots.

1.9 Audible Alarms

An audible alarm shall be installed to indicate an air conditioning failure. Each audible alarm shall have its own separate and distinct tone.

2. EQUIPMENT INSTALLATION

LINE NO.

2.1 Mechanical Interface

2.1.1 Equipment Complement

The equipments required for effective operation of the UTCS Control Center are listed in Tables IA, IB, and IC. These tables provide separate listings of UTCS Primary Equipment, UTCS Secondary Equipment and UTCS Temporary Equipment, respectively. UTCS Primary Equipment includes all data processing and data display equipment. UTCS Secondary Equipment includes all office equipment necessary to normal UTCS operation. UTCS Temporary Equipment includes additional office equipment (and space) necessary to support UTCS operation during contractor installation and checkout. Radio link monitoring provisions shall be provided.

2.1.2 UTCS Primary Equipment Physical Size

The width, depth, height and required clearances front, rear, left and right for individual UTCS Primary Equipments is provided in Table II.

2.1.3 UTCS Primary Equipment Weight and Floor Loading

The individual weight and floor loading for the UTCS Primary Equipments in both pounds per square foot and pounds per caster or jackpad is provided in Table II.

2.1.4 UTCS Primary Equipment Heat Dissipation

The heat dissipation in BTU per hour for individual UTCS Primary Equipments is provided in Table II.

2.1.5 UTCS Primary Equipment Air Circulation

The air circulation in cubic feet per minute for individual UTCS Primary Equipments is provided in Table II for each applicable equipment.

2.2 Electrical Interface

2.2.1 60 Hz Power Requirements

The type of power, KVA load, number of wires, recommended breaker and applicable connectors for the individual equipments is provided in Table II. Typical system power distribution is shown in XDS Integration Drawing 139273. Standard power connections are shown in Figure 2.

2.2.2 Telephone Lines

Provisions shall be made to accommodate a 120 channel telephone interconnection panel as close to the communication/termination equipment as practical.

2.2.3 System Grounding

A system ground bus shall be provided which shall connect directly to the transformer power source center tap. No other connections to this bus shall

LINE NO.

be made external to the room. The ground bus wire shall be insulated and at least 1/0 AWG. Individual taps from this wire to the individual equipments within the room shall be at least number 4 AWG.

Appendix A shall be used as a reference for details on the grounding system. The grounding system shall be as indicated in Appendix A or the equivalent.

TABLE IA
UTCS PRIMARY EQUIPMENT LIST

Equipment	Qty.
Sigma 5 CPU/IO	2
Sigma 5 Memory	2
Sigma 5 Mag Tape Control/Drive	2
Sigma 5 Mag Tape Drive	1
Sigma 5 Disc Control/Drive	1
Sigma 5 Disc Drive	1
Sigma 5 Card Reader	1
Sigma 5 Card Punch	1
Sigma 5 Line Printer	1
Sigma 5 Communication Interface Unit	
Sigma 5 MIOP	1
Sigma 5 KSR 35 TTY	2
Communications/Termination Cabinets	10
Map Electronics Cabinet	1
Map Display	1
Traffic Control Panel	1
CRT Display	2
Telephone Line Interconnection Panel	1
Control Console	1
Table (Card Reader)	1
Cross Reference Directory	1

LINE NO.

TABLE IB
UTCS SECONDARY EQUIPMENT

Control Center Area	Equipment	Qty.	Size h x w x d	Comments
Operations Center	Key Punch	1	TBS	
	Console Chairs	2	-	
	Tape Storage Cabinets	5	7' x 3' x 1 3/4'	5 shelves
	Card Storage Cabinets	4	3¼' x 1½' x 2½'	7 double drawer
		2	2½' x 1½' x 2½'	5 double drawer
	Telephones	2	-	Call Director Type on Console
Work Room	Work Benches	2	3' x 6' x 3'	
	Stools	2	-	
	4-drawer Memo File Cabinet	1	4' x 1¼ x 2½'	
	5-drawer Drawing File Cabinet	1	3' x 4' x 3'	
	5-shelf Storage Cabinets	4	7' x 3' x 1½'	
Office	Desks	3	2½' x 5' x 2½'	
	Desk Chairs	3	-	
	2-drawer File Cabinets	3	2½' x 1¼' x 2½'	
	Book Cases	3	3½' x 3' x 1¼'	
	Tables	1	2½' x 5' x 3'	
	Desk Calculator	1	-	
	Telephones	3	-	
Conference Room	Table	4	2½' x 5' x 3'	Butt to make 6' x 10' Table
	Conference Chairs	10	-	
	Blackboard	1	4' x 8'	
	Projection Screen	1	4' x 6'	

LINE NO.

TABLE IC
UTCS TEMPORARY EQUIPMENT*

Control Center Area	Equipment	Qty.	Size h x w x d	Comments
Adjacent Office	Desks	3	$2\frac{1}{2}$' x 5' x $2\frac{1}{2}$'	
	Desk Chairs	3	-	
	2-drawer File Cabinets	3	$2\frac{1}{2}$' x $2\frac{1}{4}$' x $2\frac{1}{2}$'	
	Bookcases	3	$3\frac{1}{2}$' x 3' x $1\frac{1}{4}$'	
	Tables	1	$2\frac{1}{2}$' x 5' x 3'	
	Desk Calculator	1	-	
	Telephones	2	-	

* This equipment is required for use by the Contractor's Washington, D.C., program manager.

TABLE II

UTCS PRIMARY
EQUIPMENT INSTALLATION DATA

Nomenclature	Dimension inches	Weight lbs	Floor Loading Per Unit	Heat Dissipation BTU/HR	Air Circulation CFM	Power Requirements
Sigma 5 CPU/IO (2)	Width 61 in. Depth 36 in. ea Height 64 in. Clearances front 30 in. rear 30 in. left 0 right 0	1800 ea 3600 total	120 lbs/sq. ft 225 lbs/ jack pad 8 jack pads	20,000 ea 40,000 total	3220 ea 6440 total	Breaker CPU 3.3 KVA 20A I/O 3.3 KVA 20A CPU 3.3 KVA 20A I/O 3.3 KVA 20A 13.2 KVA Total 208V 3Ø 5 wire Connectors 45105
Sigma 5 Memory (32K) (2)	Width 36 in. Depth 36 in. ea Height 64 in. Clearances front 30 in. rear 30 in. left 0 right 0	1000 ea 2000 total	111 lbs/sq. ft 250 lbs/ caster	N/A	N/A	N/A
Sigma 5 MIOP	Width 36 in. Depth 36 in. Height 64 in. Clearances front 30 in. rear 30 in. left 0 right 0	1000	111 lbs/sq. ft 250 lbs/ caster	10,000	1610	3.3 KVA 208V 3Ø 5 wire Breaker 20A Connector 45105

Table II. (Continued)

Nomenclature	Dimension inches	Weight lbs	Floor Loading Per Unit	Heat Dissipation BTU/HR	Air Circulation CFM	Power Requirements
KSR 35 TTY (2) For use with Sigma 5	Width 20 in. ea Depth 24 in. ea Height 39 in. ea Clearance front 0 rear 9 in. left 0 right 0	136 ea 272 total	39 lbs/sq. ft total 68 lbs/leg each	1200 ea 2400 total	 N/A	1.0 KVA Total 120V 1Ø 3 wire Connector 5251
7361/7362 Magnetic Control Drive (2)	Width 30 in. Depth 35 in. Height 64 in. Clearances front 31 in. rear 31 in. left 0 right 0	950 ea 1900 total	 152 lbs/sq. ft 238 lbs/caster	4400 ea 8800 total	850 ea 1610 total	2.3 KVA 120V 1Ø 3 wire Connector 3120 Breaker 30A
7362 Magnetic Tape Drive Slave	Width 30 in. ea Depth 35 in. ea Height 64 in. ea Clearances front 31 in. rear 31 in. left 0 right 0	915	120 lbs/sq. ft 229 lbs/caster	3200	690 ea	1.0 KVA Total 120V 1Ø 3 wire (2) Connectors 3120 (2) Breakers 30A

Table II. (Continued)

Nomenclature	Dimension inches	Weight lbs	Floor Loading Per Unit	Heat Dissipation BTU/HR	Air Circulation CFM	Power Requirements
RAD (DISK) Control 7203	Width 33 in. Depth 36 in. Height 64 in. Clearances front 31 in. rear 31 in. left 0 right 0	1100	183 lbs/sq. ft 275 lbs/caster	5400	690	1.8 KVA 208V 3Ø 5 wire Connector 45105 Breaker 15A
RAD (DISK) Slave 7204	Width 33 in. Depth 36 in. Height 64 in. Clearances front 31 in. rear 31 in. left 0 right 0	900	144 lbs/sq. ft 225 lbs/caster	4000	690	1.2 KVA 208V 3Ø 5 wire Connector 45105 Breaker 15A
7122 Card Reader	Width 27 in. Depth 32 in. Height 17 in. Clearances front 0 rear 20 in. left 17 in. right 0	200	Sets on table	2616	N/A	0.9 KVA 120V 1Ø 3 wire Connector 3120 Breaker 15A

Table II. (Continued)

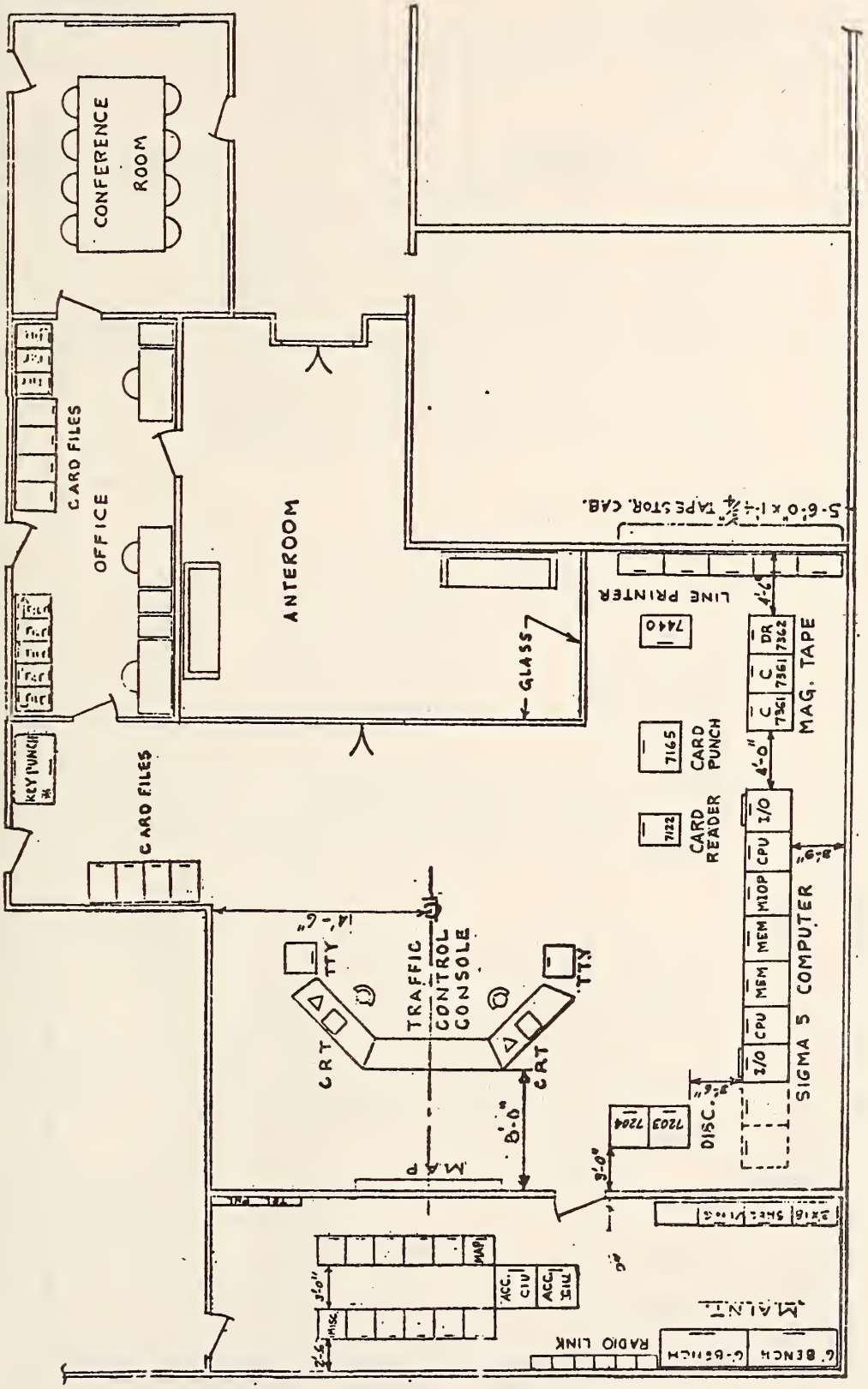
Nomenclature	Dimension inches	Weight lbs	Floor Loading Per Unit	Heat Dissipation BTU/HR	Air Circulation CFM	Power Requirements
7165 Card Punch	Width 38 in. Depth 33 in. Height 40 in. Clearances front 14½ in. rear 0 sides 0	480	53 lbs/sq. ft 120 lbs/caster	2860	230	1.1 KVA 120V 1Ø 3 wire Connector 3120 Breaker 20A
7440 Line Printer	Width 39 in. Depth 25 in. Height 53 in. Clearances front 39 in. rear 38 in. left 24 in. right 24 in.	900	129 lbs/sq. ft	3228	460	1.2 KVA 120V 1Ø 3 wire Connector 3120 Breaker 30A
Sigma 5 Accessory (CIU) (2)	Width 36 in. Depth 36 in. Height 64 in. Clearances front 30 in. rear 30 in. left 0 right 0	600 ea 1200 total	65 lbs/sq. ft 150 lbs/caster	3120	1610	2.0 KVA 120V 1Ø 3 wire Connector 3120 Breaker 30A

Table II. (Continued)

Nomenclature	Dimension inches	Weight lbs	Floor Loading Per Unit	Heat Dissipation BTU/HR	Air Circulation CFM	Power Requirements
Communication/ Termination Equipment (Est. 16-18 cabinets)	Width 24 in. ea Depth 24 in. ea Height 66 in. ea Clearances front 12 in. rear 24 in. left 0 right 0	(Est.) 400 ea TBA 6400 (16) total	100 lbs/sq. ft	2004 54 254 5950 (Est) 8262 total	N/A	115V 1Ø 3 wire Rcvrs. 0.60 KVA Xmtrs. 0.02 KVA P.S. 0.15 KVA Misc. 1.75 KVA total 2.52 KVA 10 duplex outlets
Map Display	(Approx.) Width 10 ft Depth 6 in. Height 6 ft 6 in.	(Est.) 493 wall mounted	N/A	(Est) 5800	N/A	1.7 KVA 120V 1Ø 3 wire 120 via electronics cab.
Map Electronics Cabinet	Width 24 in. Depth 24 in. Height 66 in. Clearances front 24 in. rear 24 in. left 0 right 0	(Est.) 313	78 lbs/sq. ft	(Est) 2048	N/A	0.6 KVA 120V 1Ø 3 wire 2 duplex outlets for 2.3 KVA total

Table II. (Continued)

Nomenclature	Dimension inches	Weight lbs	Floor Loading Per Unit	Heat Dissipation BTU/HR	Air Circulation CFM	Power Requirements
Console	TBA	C.P. 50 CRT(2)146 Console TBA	TBA	C.P. Est. 341 2,400 2,741 Total	N/A	0.1 KVA (C.P.) 0.7 KVA (CRT-2) 0.8 KVA Total 120V 1Ø 3 wire 2 duplex outlets



RECOMMENDED UTCS FACILITY EQUIPMENT
LAYOUT
WASHINGTON D.C.

FIGURE 1

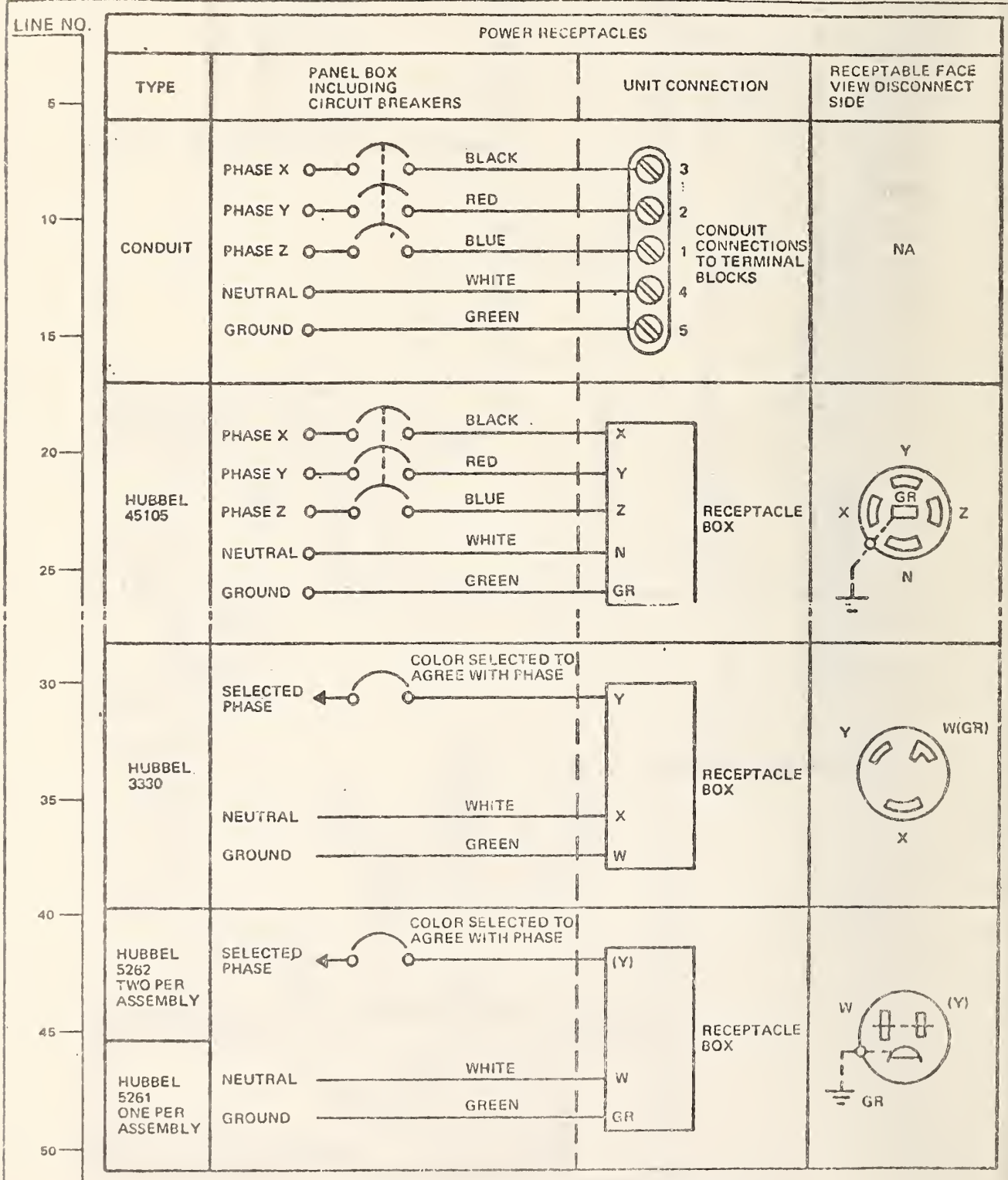


Figure 2. Required Power Receptacles

LINE NO.

5
10
15
20
25
30
35
40
45
50

APPENDIX A

LINE NO.

GROUNDING STRUCTURE

1. Ground System, Power Source. Ground integrity starts with the high voltage power distribution transformer from which the computer receives power. A special transformer for the computer and related interface electronics is preferred. However, if this section is used as a guide for ground connections, no problems should be encountered.

In the following figures, ground wires and neutral wires are to be the same size as the power wire with which they are routed.

In high power consuming systems, the grounding discussion must include the power transformer provided by the utility company. This transformer, in addition to a voltage conversion, provides a degree of isolation from noise of other consumers connected to the same lines. The common or neutral (N) is grounded as close to the power transformer as possible.

The Sigma system should obtain all voltages, and their return lines, and grounds from a power panel board. This board is to provide buses for this purpose along with circuit breakers. Earth connections between transformer and panel board are shown in figure 1. Also shown is an earth ground plane which is the primary ground source.

If multiple power panels are to be connected in sequence, the same neutral current mentioned above is now the resultant of all equipments in the sequence. Interaction due to this current may cause interruption of operation to the computer unless the approach is part of a carefully planned power bus complex. Proper care should be exercised when connecting signal wires between the computer and other equipments due to the differential voltages encountered. Figure 1-2 is preferred. Again local electrical codes may not permit this approach.

Figure 1-1. The neutral and ground wires are returned separately to Ground. (This circuit is optimum.)

Again, this approach must be part of a carefully planned power bus complex with due consideration to other equipments served and to all signal interconnections between equipments in the sequence.

Figure 1-3. If more than one panel board is to be serviced by one transformer, the preferred method is to parallel them at the transformer terminals. This reduces interaction to a minimum.

Wherever many earth grounds are required, the water pipe would have to be considered as a significant part of the wiring. To prevent complications, an earth ground plane should be constructed which takes into consideration equipments to be served and conductivity of the soil.

If the wire connecting the system and the Ground Plane is long, a grouping approach may be used as shown by "First Ground Plane." Again, care should be taken in grouping, as equipments sharing the same line may interact.

If multiple ground counterpoises are employed, all signal interconnections between equipments serviced by them must be evaluated on the basis of isolation or noise rejection capability of their communicating elements.

Electrical conduit is not to serve as a ground wire in any instance, unless it is approved by SSMD Engineering.

2. Ground system, computer panel board. The computer panel board is to be devoted exclusively to the computer, and directly associated interface equipment It must provide a bus structure for termination of grounds, and a separate structure for termination of "neutral" lines. One set of one neutral and one ground terminal must be provided for each circuit breaker (single phase) and one set for each multiple pole circuit breaker (three phase). Two additional ground terminals are required to ground system interface unit cabinets if they are part of the installation.

3. Ground system, load side of computer panel board. This involves all aspects of panel board to unit, and unit to unit connections. A load is a power distribution panel associated with a Sigma cabinet, or a peripheral device.

a. Neutral wires. The relationship between the "neutral" lines and ground has been established previously. To preserve this relationship, no neutral may be connected to a cabinet, power or signal ground at any point in this section. Neutral is to be regarded as a "power return" to units to which it is connected.

The return wire is to be the same size as the "hot" wire, whether single or three phase. The return wire is to be routed directly to the power panel, with its hot wire(s), and connected to the neutral line terminal provided as in paragraph 2.

Return wires shall not be collected into "nodes" to conserve wire because:

(1) Power values specified are for a certain condition and may fluctuate drastically under dynamic conditions; and

(2) The number of units with power applied may change with operational circumstances, equipment failures, and equipment add-ons or deletions.

If with SSMD Engineering approval, it is decided that return wires are to share a common conductor, the circular mil measurement of the common conductor must be the same as the sum of the circular mil measurements of the individual return wires specified. However, the common need not be larger than the service wire supplying the power panel.

b. Equipment Ground. Each load connected to the power panel has an additional wire (green) for grounding purposes. The ground wire from each load should be routed to the power panel and connected to the ground terminals provided. The conduit ground should not be used for this purpose. Ground returns may not share a common wire in route to power panel. The ground wire should be

LINE NO.

the same size as the power wires to a given unit, however, it may be decreased to number 8 gage if necessary. A load may be a power distribution panel from a Sigma cabinet, or a peripheral device..

c. A ground strap is to provide a dependable cabinet-to-cabinet ground on all cabinets that are bolted together.

d. System interface unit cabinet grounds. The SIU cabinet may contain both digital and analog devices. The digital grounds are collected at a digital ground terminal, and the analog grounds are collected at an analog ground terminal. The two ground terminals are to be connected directly and independently to the two "additional terminals" of paragraph 2 using a number 8 gage wire.

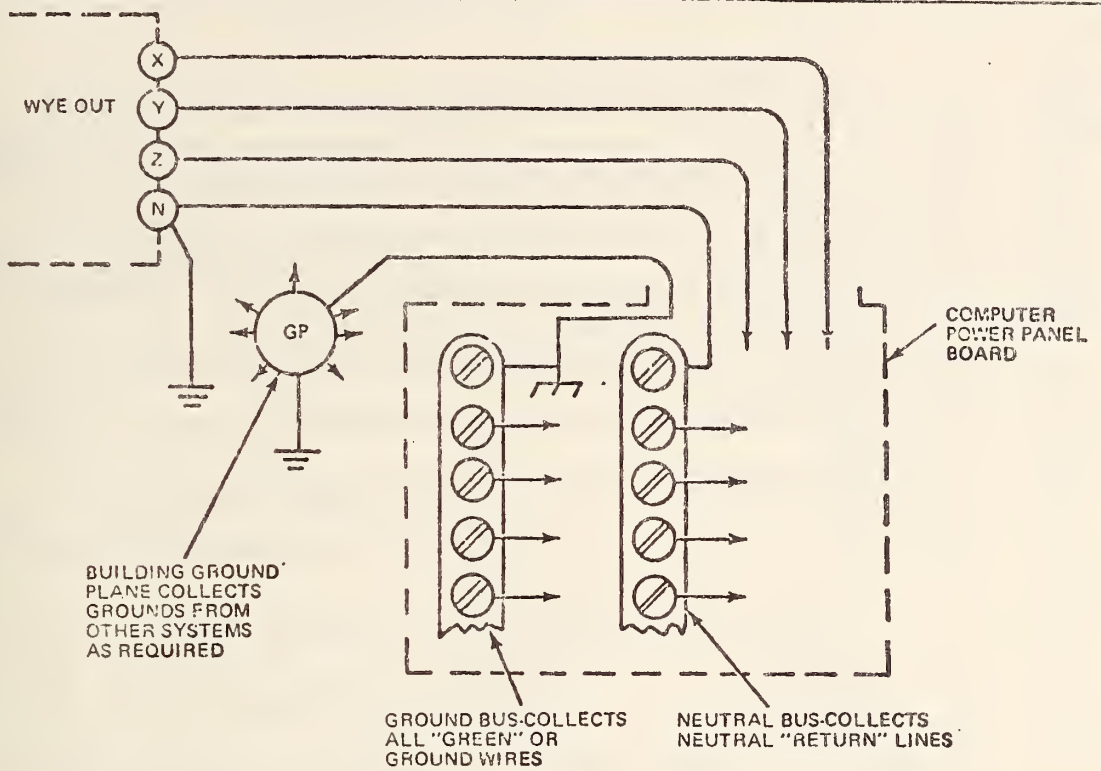
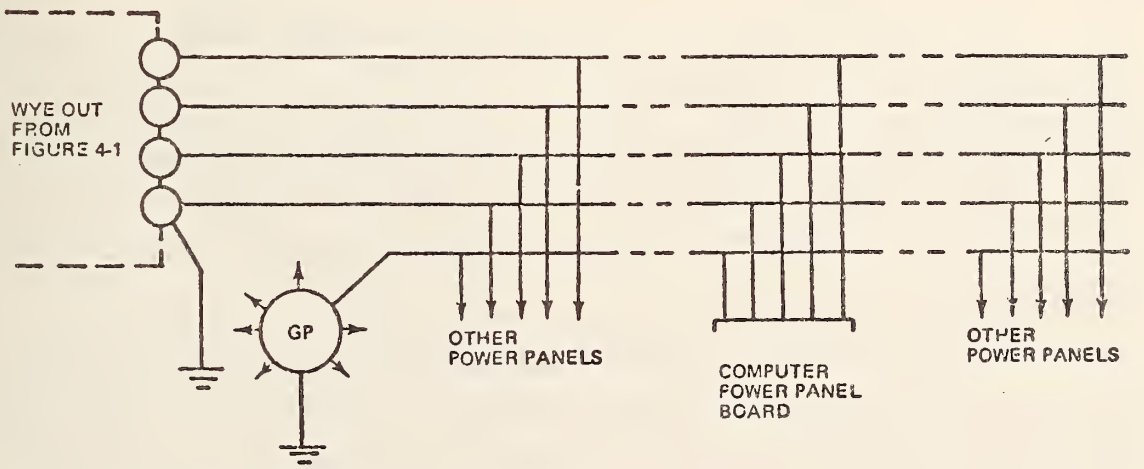


Figure A-1. Connections When Ground and Neutral are Provided on Separate Lines



NOTE: NEUTRAL AND GROUND MAY BE TIED TOGETHER AT ONE POINT ONLY. NO INTERCONNECTION IS PERMITTED IN ANY POWER PANEL BOARD

Figure A-2. "Power Bus" Complex

LINE NO.

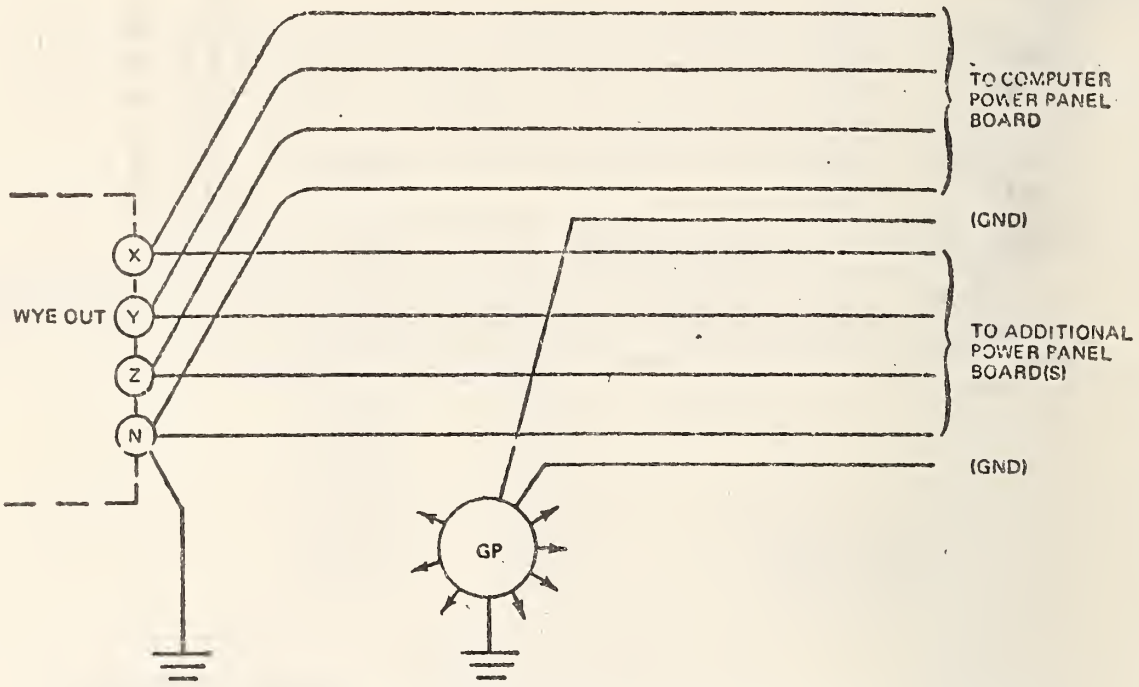


Figure A-3. Preferred Method of Multiple Load Connections to Transformer

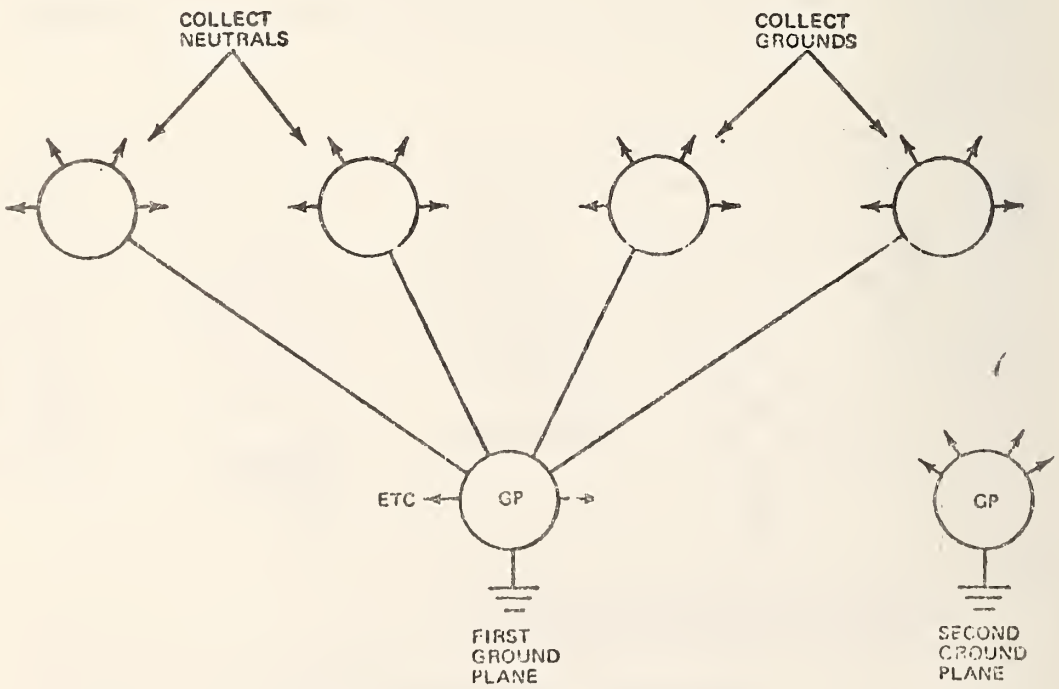


Figure A-4. Multiple Branches from Ground Plane

SM 549-1

APPENDIX E

UTCS ACCEPTANCE TEST PLAN

This document and its attachments outline procedures for the UTCS Acceptance Tests. These tests will demonstrate UTCS operational readiness for full system operation utilizing first-generation software, and will form a basis for system acceptance by the FHWA. Preceding the tests there will be a period of hardware, subsystem, and overall system debugging and integration. The acceptance test procedures are predicated on the previous verification of proper component interconnection and operation. The acceptance tests do not include any integration procedures and are concerned solely with the clear demonstration of necessary UTCS system functions, as specified in the contract FH-11-7605.

The acceptance tests have been designed to verify the following major UTCS system functions by means of field observations:

- Computer-controlled time-of-day operation (Test A)
- MOE computations (Test B)
- CIC operation (Test C)
- BPS operation (Test D)
- Pattern match operation (Test E)

All operational system tests specified in paragraph 6.4 of the Schedule for the UTCS contract (FH-11-7605) will be included. Local controller operation (paragraph 6.4a) will have been previously verified during the controller installation phase. All necessary operator control functions will be exercised as part of the test procedures.

Outlines of test procedures for each of the 5 major UTCS system functions are attached. The outlines for the tests are organized to specify the purpose, test procedures, data requirements, and test results in each case. Step-by-step procedures will be defined for each test, and will be submitted to FHWA for review prior to conducting the actual tests. As tests are completed, data sheets will be submitted to FHWA for sign-off indicating successful completion of the test.

UTCS ACCEPTANCE TEST A
COMPUTER-CONTROLLED TIME-OF-DAY OPERATION

A-1. SINGLE-CONTROLLER OPERATION

Purpose

Verify computer control of single controller by field observations.

Test Procedure

1. Run tests in early morning hours at selected controller.
2. Observe at least 10 controller cycles while on local control (peak dial #2 or #3 manually selected at controller), noting clock times at which red, green, and amber intervals are initiated.
3. Observe at least 10 controller cycles while on computer control (TOD pattern), noting clock times at which red, green, and amber intervals are initiated. (Computer-controlled cycle should exhibit different cycle, split, and offset than local cycle.)
4. While under computer control, implement a split change. Verify that a change is effected by field and central observations.
5. While under computer control, implement an offset change. Verify that a change is effected by field and central observations.
6. Change to local control and verify that cycle, split, and offset revert to local dial.

Data Requirements

1. Record red, green, and amber interval start times in field for both local and computer-controlled cycles for a minimum of 10 cycles.
2. Record offsets (relative to an adjacent controller under local control) for both local and computer-controlled cycles.
3. Record time of computer takeover and time computer control is relinquished at central site.

4. Record red, green, and amber interval start times in field for a minimum of three cycles after operator split change is implemented.

5. Record offset (relative to adjacent controller under local control) for a minimum of three cycles after operator offset change is implemented.

6. Verify operator split change by observing interval changes on CRT Intersection Status display.

7. Verify operator offset change by observing offset changes on CRT Intersection Status display.

8. Verify time of occurrence and duration of A-phase green by observing map display.

9. Verify computer takeover by observing controller status on map and CRT.

Test Results

1. Field and central data shall verify shift of controller cycle from local to computer control and subsequently back to local operation.

2. Field and central data shall verify operator split and offset change operation.

A-2. MULTI-CONTROLLER OPERATION

Purpose

Verify computer control of three controllers in two UTCS sections by field observations.

Test Procedure

The test procedure for this test is the same as for Test A-1, except three controllers are involved, and operator split and offset changes are not required.

If possible, controllers shall be selected to be in two UTCS sections, but at adjacent intersections, so that simultaneous observation is possible.

Data Requirements

The data requirements are the same as for Test A-1, except three controllers are involved and operator split and offset changes are not required.

Test Results

The test results shall be the same as for Test A-1, except three controllers are involved and operator split and offset changes are not required.

UTCS ACCEPTANCE TEST B
MOE VERIFICATION

B-1. VOLUME/SPEED VERIFICATION

Purpose

Verify volume and speed MOE computations by field observations.

Test Procedure

1. The tests encompass a minimum period of 15 minutes, or an integral number of successive controller cycles encompassing a 15-minute period.

2. Field observations of speed and volume are obtained each cycle over the test period.

3. A radar speed meter is set up in the vicinity of the detector for the link under test.

4. Concurrent observations are made at Central via the CRT Intersection Status display and the 15-minute system report.

Data Requirements

1. Record total of all vehicles travelling through link for each cycle of the 15-minute period synchronized with Central.

2. Record the speed indicated by the radar speed meter for each vehicle crossing the detector during the test period.

3. Record the volume and speed, as indicated by the CRT display, for each cycle.

4. Obtain a 15-minute system report for the test period.

Test Results

1. The average of the volumes indicated by the CRT for the total number of cycles shall agree with the volume in vehicles per hour observed during the 15-minute

test period to within ± vehicles per hour or ± percent, whichever is greater.

2. The volume in vehicles per hour indicated in the 15-minute report for the link under test shall agree with the observed total volume over the 15-minute period, extrapolated over an hour, to within ± vehicles per hour or ± percent, whichever is greater.

3. The average of the speeds indicated by the CRT for the total number of cycles shall agree with the average speed in miles per hour of all radar speed observations over the 15-minute test period to within ± miles per hour or ± percent, whichever is greater.

4. The speed in miles per hour indicated in the 15-minute report for the link under test shall agree with the observed average of all radar speed observations over the 15-minute test period to within ± miles per hour or ± percent, whichever is greater.

B-2. QUEUE AND STOPS

Purpose

Verify que e and stops MOE computations by field observations.

Test Procedure

1. The test encompass a minimum period of 15 minutes, or an integral number of succe sive controller cycles encompassing a 15-minute period.

2. Field o servations of queue and stops are obtained for each cycle over the test per d. Queue is defined as the number of vehicles, including moving
he start of green. Stops is defined as the number of
during the cycle, beginning with the start of
f he next cycle.

ia the CRT Intersection Status

Data Requirements

1. Record the queue in the link at the start of green for each cycle of the 15-minute period synchronized with Central.

2. Record the total number of stopped vehicles in the link for each cycle of the 15-minute test period.

3. Record the queue and stops, as indicated by the CRT display, for each cycle.

4. Obtain a 15-minute system report for the test period.

Test Results

1. The average of the queues indicated by the CRT display for the total number of cycles shall agree with the average queue in vehicles per cycle observed over the 15-minute test period to within ± vehicles per cycle.

2. The queue in vehicles per cycle indicated in the 15-minute report for the link under test shall agree with the observed average queue to within ± vehicles per cycle.

3. The average of the stops, indicated by the CRT display for the total numbers of cycles, shall agree with the average stops per cycle observed over the 15-minute test period to within ± stops per cycle.

4. The total number of stops indicated on the 15-minute report for the link under test shall agree with the observed total number of stops to within ± stops or ± percent, whichever is greater.

B-3. DELAY

Purpose

Verify delay MOE computations . . eld observations.

Test Procedure

1. The tests encompass a period of 15 minutes, or an integral number of successive controller cycles encompassing a 15-minute period.

2. Field observations of queue at red and green are obtained for each cycle over the test period. The queue at red or green is defined as the number of vehicles, including moving vehicles, in the link.

3. Concurrent observations are made at Central via the CRT Intersection Status display and the 15-minute report.

Data Requirements

1. Record the queue at the start of red and green for each cycle of the 15-minute test period synchronized with Central.

2. Record the delay, as indicated by the CRT display, at the next refresh cycle following the end of the 15-minute test period.

3. Obtain a 15-minute report for the test period.

Test Results

1. Compute the total delay for each cycle in terms of the observed red and green queues and the appropriate stored link parameters.

2. The sum of the delays computed from field queue measurements for the total number of cycles shall agree with the delay indicated by the CRT display to within ± seconds or ± percent, whichever is greater.

3. The sum of the delays computed from field queue measurements for the total number of cycles, divided by the total number of vehicles indicated in the 15-minute report for the link, shall agree with the delay in seconds per vehicle indicated in the 15-minute report to within ± sec/veh. or ± percent, whichever is greater.

B-4. OCCUPANCY

Purpose

Verify occupancy MOE computations by observing detector pulse widths at Central.

Test Procedure

1. The test encompasses a period of 15 minutes, or an integral number of successive controller cycles encompassing a 15-minute period.

2. The pulse width, in seconds, of all detector actuations for the link under test is measured at Central. Measurements are made at the communications receiver (D.C. output), utilizing either an oscilloscope (or oscilloscopes) whose sweep is triggered externally by the detector pulses, or an electronic counter (or counters) with a period function.

3. Observations of occupancy are made via the CRT Intersection Status display and the 15-minute report.

Data Requirements

1. Record the pulse width of all detector actuations on the link under test over a 15-minute test period.

2. Record the occupancy displayed on the CRT for each cycle encompassing the 15-minute period.

3. Obtain a 15-minute report for the test period.

Test Results

1. Compute the sum of the pulse widths for the total of all detector actuations over the test period.

2. The percent occupancy computed from the sum above for a 15-minute period shall agree with the percent occupancy indicated in the 15-minute report for the link to within ± percent or ± percent of the measured percent occupancy, whichever is greater.

3. The percent occupancy computed from the sum above for a 15-minute period shall agree with the average of the occupancy values, observed on the CRT display for each cycle over the 15-minute period, to within ± percent or ± percent of the measured percent occupancy, whichever is greater.

UTCS ACCEPTANCE TEST C

CIC OPERATION

Purpose

Verify CIC operation on selected links in response to queue and volume demands observed in the field.

Test Procedure

1. Run tests at a selected intersection during periods for which peak queues are expected on a major phase of traffic flow.

2. Field observations of queue and volume at each of the instrumented multi-detector links at the intersection are obtained over the test period.

3. Concurrent observations are made at Central via the CRT Intersection Status display.

4. The tests encompass a minimum of 10 successive controller cycles.

5. If a split change favoring a phase of traffic is not indicated over 10 cycles (CIC not operating above threshold), observations continue over successive cycles until such time as CIC operation above threshold is indicated ("THLD" indicated on CRT).

Data Requirements

1. Record green and red start times in the field for the instrumented phases for each cycle.

2. Record observed queue (all vehicles within link) at start of green for each cycle for all multi-detector links.

3. Record number of vehicles, each cycle, which leave link (crossing Q_1) during green phase for all multi-detector links.

4. Record CIC status and phase durations as a function of time as indicated on the CRT Intersection Status display at Central.

Test Results

1. Cycle split shall favor the phase for which the green demand threshold is exceeded.

UTCS ACCEPTANCE TEST D
BPS OPERATION

Purpose

Verify that green extension times are properly granted and accepted by buses.

Test Procedure

1. Run tests at a selected intersection during which peak traffic is expected on the phase associated with the bus zone (or zones) under test.

2. Send bus (or car with bus transmitter) over bus loops in eligible and non-eligible cycle periods using Stop Bus mode.

3. Field observations of queues on multi-detector links at the intersection are obtained in conjunction with test vehicle arrivals at the upstream bus detector.

4. Observe cycle intervals to verify award or refusal of green extension.

5. Observe BPS data displayed for each test intersection on CRT (BPS Intersection Status page).

6. The tests encompass a minimum of 10 successive controller cycles.

7. If an extension is not granted over 10 cycles (intersection gain threshold not exceeded, or test vehicle has not arrived during eligible period, or BPS is inhibited dur to link operation as a CIC), observations continue over successive cycles until such time as a bus extension is granted.

8. Repeat above procedure for Thru Bus mode.

Data Requirements

1. Record zone entry times for buses and times for start of controller red, green, and amber intervals in field.

2. Record the queue at the start of green for each multi-detector link at the intersection.

3. Record BPS data displayed on CRT for intersections involved.

4. Verify intersection BPS operation by observing BPS status on map display.

5. Obtain 15-minute report(s) encompassing the test period.

Test Results

1. Green extensions shall be granted during eligible bus entry periods.

2. Helped bus MOE and intersection gain MOE displayed on the CRT and 15-minute reports shall correlate with field observations.

UTCS ACCEPTANCE TEST E
PATTERN-MATCHING OPERATION

Purpose

Verify pattern-matching operation in selected UTCS sections in response to morning rush-hour volume and occupancy demands.

Test Procedure

1. Impose off-hour traffic control pattern on test section before start of rush hour.
2. Observe traffic flow at three selected intersections in field to verify normal traffic conditions.
3. Observe switchover to morning rush-hour pattern.
4. Repeat procedure for one other UTCS section.

Data Requirements

1. Record volume data for at least three selected intersections in section. Take data from CRT Intersection display for selected intersections.
2. Record pattern numbers imposed and time of shift to rush-hour pattern and verify by observing the 15-minute report on line printer and Intersection Status page on CRT.

Test Results

1. Pattern change should occur as traffic builds up towards rush hour peak.

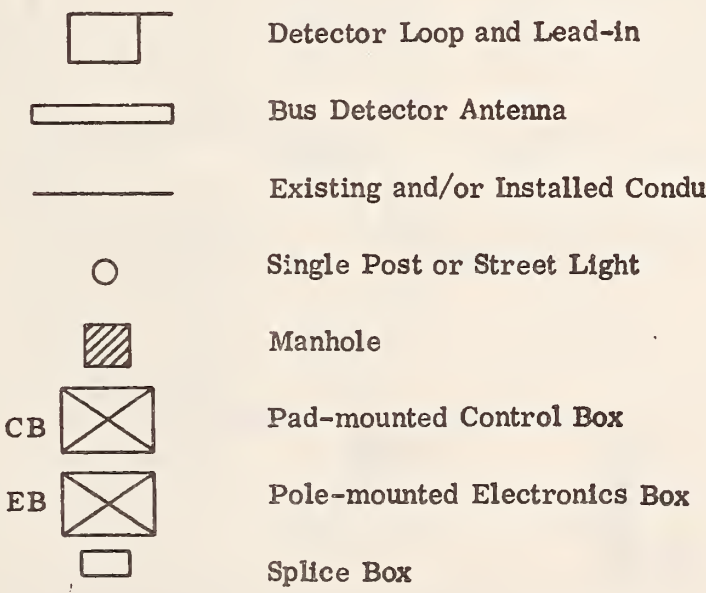
APPENDIX F

SAMPLE UTCS/BPS INSTALLATION REFERENCE DOCUMENTS

This appendix includes sample sheets of 10 reference documents which have been used to organize and keep track of the UTCS/BPS installation. These include:

SSMD Document No.	Title
4200	UTCS Installation Drawing, 35 sheets
4-2002	Loop Installation
4-2003	Field Equipment Complement Summary
4-2004	Vehicle Detector Loop Index
4-2005	Bus Detector Loop Index
4-2006	Computer Map Link Cross Reference
4-2007	EB Index
4-2008	UTCS Multiplex Plan
4-2009	Channel Frequency Allocation
4-2011	Central Communication Cabinet Module Identification

The documents have been kept up-to-date and reflect the current UTCS/BPS configuration. UTCS Installation Drawing, UTCS-4200, 35 sheets, provided the details for the street installation. Sheet 3 is included here for reference. The legend describing the various symbols used is included in sheet 1. They are listed here again for convenience, as follows:



Detector Loop and Lead-in

Bus Detector Antenna

Existing and/or Installed Conduit

Single Post or Street Light

Manhole

Pad-mounted Control Box

Pole-mounted Electronics Box

Splice Box

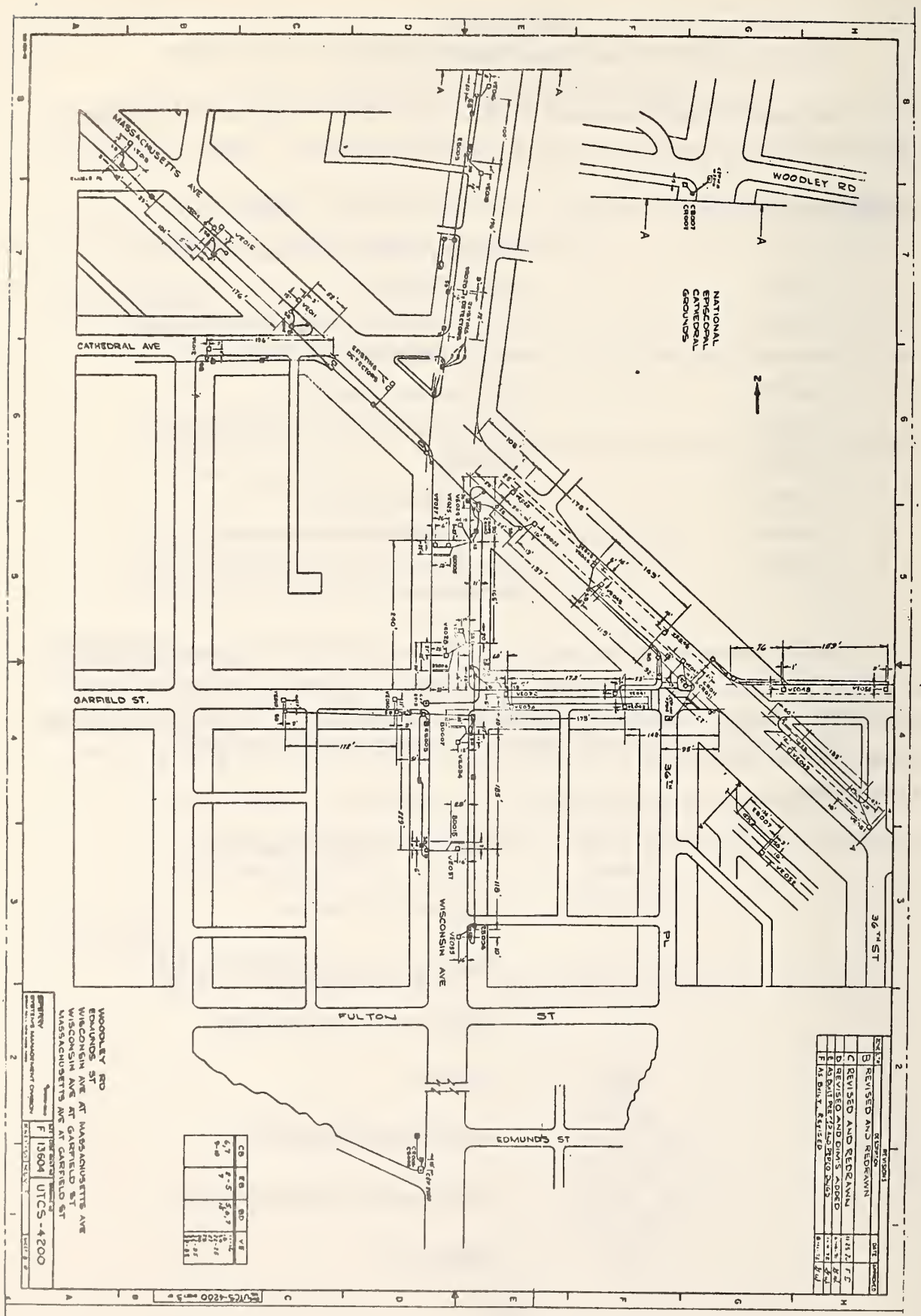

WOODLEY RD
MASSACHUSETTS AVE
CATHEDRAL AVE
GARFIELD ST.
NATIONAL EPISCOPAL CATHEDRAL GROUNDS
WISCONSIN AVE
36TH ST
PL
FULTON
ST
EDMUNDS ST
WOODLEY RD
EDMUNDS ST
WISCONSIN AVE AT MASSACHUSETTS AVE
WISCONSIN AVE AT GARFIELD ST
MASSACHUSETTS AVE AT GARFIELD ST
SPERRY
F 13604
UTCS-4200
REVISIONS
B REVISED AND REDRAWN
C REVISED AND REDRAWN
D REVISIONS ADDED
E As Built 8/22/72
F As Built 5/15/80

TABLE IN-2. LOOP INSTALLATION

Street	Direction	Lane	Detection Function and Number	Distance from Stop Line (feet)	Detector Electronics Location	Control Box Number and Remarks
L	E/B	2	Q_1 (408)	35	L & 14 (W. Side)	EB025
L	E/B	2	Q_2 (368)	190	L & Vermont	CB096
L						
L						
L						
14	N/B	2	Q_1(383)	35	L & 14	CB097
14	N/B	-	B_1 (134)	25	L & 14	CB097
14	N/B	2	Q_2 (403)	210	L & 14	CB097
14	N/B	2	Q_3 (251)	295	K & 14	CB099
14	N/B	-	B_2 (136)	210	L & 14	CB097
14	S/B	2	Q_1 (410)	35	L & 14 (W. Side)	EB025
14	S/B	-	B_1 (137)	25	L & 14 (W. Side)	EB025
14	S/B	2	Q_2 (412)	210	L & 14 (W. Side)	EB025
14	S/B	2	Q_3 (421)	320	L & 14 (W. Side)	EB025
14	S/B	-	B_2 (138)	210	L & 14 (W. Side)	EB025
L	E/B	2	V_1 (456)	210	L & Vermont	CB096
L	E/B	2	V_1 (407)	40	L & 14 (W. Side)	EB025
Vermont	N/B	2	V_1 (223)	210	K & 15/Vermont	CB100
Vermont	S/B	2	V_1 (375)	210	L & Vermont	CB096
L	E/B	2	V_1 (454)	210	L & 15	CB083
L	E/B	2	V_1 (457)	112	L & Vermont	CB096
15	N/B	3	V_1 (451)	210	L & 15	CB083
15	N/B	2	V_1 (452)	210	L & 15	CB083

TABLE IN-3. FIELD EQUIPMENT COMPLEMENT SUMMARY

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications			Remarks
					3F Rec.	3F Tr.	2F Tr.	
CB001	M & 30 St.	FT-19-3-16	0	0	1	0	1	
CB002	Wisc & Whitehaven	FT-19-3-16	0	0	1	0	1	
CB003	Wisc & 34 St.	FT-19-3-18	0	0	1	0	1	
CB004	Wisc & Porter	FT-19-3-18	0	0	1	0	1	
CB005	Wisc & Newark	FT-19-3-18	0	0	1	0	1	
CB006	Wisc & Edmunds	Semi	0	0	1	0	1	
CB007	Wisc & Woodley	FT-19-3-16	0	0	1	0	1	
CB009	Wisc & Mass E. Side	FT-40-1-16	5	1	1	1	14	
EB002	Mass bet. Cath & Klingle	None	5	0	0	0	0	Comm. in CB009
EB003	Wisc N. of Cath	None	3	0	0	0	0	Comm. in CB009
CB010	Wisc & Garfield	FT-19-1-18	5	2	1	3	11	
EB004	Wisc S. of Garfield	None	1	0	0	0	0	Comm. in CB010
EB005	Wisc & Garfield W. Side	None	3	1	0	0	0	Comm. in CB010

Veh. Loop Dwg.	Det. No. Comp	Det. Electronics Location		4200 Dwg. Sheet #	Cont-roller Cab. #	Comm. Cab. #	Tel. Pr.		Central Comm. Cab. #	
		Cab. #	Street				No.	Chan.	Cab. #	Pos.
1	501	123	Wisc & W	35	123	123	6	5	9	H12
2	500						6	11		G12
3	496						6	12		C12
4	497						6	13		D12
5	499						6	14		F12
6	498	123	Wisc & W	35	123	123	6	15		E12
7	488	121	Wisc & Calvert	34	121	121	5	4		E11
8	489						5	5		F11
9	490						5	10		G11
10	491	121	Wisc & Calvert	34	121	121	5	11	9	H11
11	9	EB2	Wisc & Mass at Cathed	3	9	9	3	8	1	D8
12	7	EB2	Wisc & Mass at Cathed					9		B8
13	11	EB2	Wisc & Mass W of Cath					10		F8
14	8	EB2	Wisc & Mass W of Cath					11		C8
15	10	EB2	Wisc & Mass W of Cath					12		E8
16	14	EB3	Wisc & Mass N of Cath	3	9	9	3	13	1	I8
17	493	EB36	Wisc & Calvert (NWC)	34	121	121	5	12	9	J11
18	13	EB3	Wisc & Mass N of Cath	3	9	9	3	14	1	H8
19	492	EB36	Wisc & Calvert (NWC)	34	121	121	5	13	9	I11
20	12	EB3	Wisc & Mass N of Cath	3	9	9	3	15	1	G8
21	494	EB36	Wisc & Calvert (NWC)	34	121	121	5	14	9	K11
22	34	9	Wisc & Mass (SWC)	3	11	9	3	1	1	I10
23	2	9			9	9		3		G7
24	5	9			9	9		4		J7
25	24	9	Wisc & Mass (SWC)	3	10	9	3	5	1	I9
26	495	EB36	Wisc & Calvert (NWC)	34	121	121	5	15	9	B12
27	22	9	Wisc & Mass (SWC)	3	10	9	3	7	1	G9
28	23	10	Wisc & Garfield	3	10	10	4	1	1	H9
29	137	EB39	Constit. & 17th	12	42	42	53	10	3	J9
30	6	10	Wisc & Garfield	3	9	10	4	4	1	K7

Bus Det. Loop # Dwg.	Comp.	Det. Receiver Location Cab#	Street	Dwg. Sheet #	Controller Cab. #	Comm. Cab. #	Tel. Pr. No.	Chan.	Central Comm. Loc. Cab. #	Pos.
1	144	123	Wisc. & W	35	123	123	6	6	9	D6
2	143							7		J5
3	141							8		F5
4	142	123	Wisc. & W	35	123	123	6	9	9	H5
5	4	9	Wisc. & Mass	3	10	9	3	6	1	H3
6	3	10	Wisc. & Garfield	3	10	10	4	6		F3
7	1	10	Wisc. & Garfield	3	10	10	4	7		B3
8	8	12	Wisc. & R	4	12	12	7	6		F4
9	7	12						7		D4
10	6	EB8						8		B4
11	5	EB8	Wisc. & R	4	12	12	7	9		J3
12	11	17	Wisc. & M	6	17	17	8	6		B5
13	9	17		6	17	17	8	7		H4
14	13	17	Wisc. & M	6	17	17	8	8		F5
15	2	EB5	Wisc. & Garfield	3	10	10	4	8		D3
16	12	EB10	M St., West of Wisc.	6	17	17	8	9		D5
17	14	EB11	Wisc. & Prospect	6	17	17	8	10		H5
18	10	18	M & 31	6	17	18	10	6	1	J4
19	137	121	Wisc & Calvert	34	121	121	5	6	9	H4
20	138	121				121		7		J4
21	139	EB36				121		8		B5
22	140	EB36	Wisc & Calvert	34	121	121	5	9	9	D5
23	21	42	Constit. & 17	12	42	42	53	6	2	J3

SSMD Document No. 4-2006
Computer Map Link Cross Reference
Date: 14 May 1971

Comp. Link No.	4202 Dwg. Map Link No.	Link Corresp. Code	4200 Dwg. Sheet No.
1	025	0	5
2	023	0	5
3	024	0	5
4	022A	0	5
5	022	0	5
6	029 *	1	6
7	029	0	6
8	028	0	6
9	027 *	1	6
10	027	0	6
11	026	0	6
12	031	0	6
13	030	0	6
14	033	0	7
15	032	0	7
16	036	0	7
17	034	0	7
18	035	0	7
19	008 *	1	3
20	008	0	3
21	007	0	3
22	006	0	3
23	009 *	1	3
24	009	0	3
25	005	0	3

Comp. Link No.	4202 Dwg. Map Link No.	Link Corresp. Code	4200 Dwg. Sheet No.
251	111	0	15
252	247	0	32
253	246	0	32
254	249	0	32
255	248	0	32

* Indicates two parallel links are assigned to the same map indicator link no.

Link correspondence code:

"0" - indicates one to one correspondence between computer link number and map link indicator numbers

In the case of parallel links, the "0" indicates that the volume, occupancy, and speed parameters for this link are applicable for the map display.

"1" - indicates that the volume, occupancy, and speed parameters for this link are to be ignored for the map display.

EB No.	Intersection	4200 Dwg Sheet No.	VE Nos.	BD Nos.	Comm. Cab No.
1	19th, N. of L	23	466, 467	108	84
2	Mass, betw. Cath. & Klingle	3	13, 14, 15, 11, 12		9
3	Wisc., N. of Cath.	33	16, 18, 20		9
4	Wisc., S. of Garfield	33	35		10
5	Wisc. & Garfield, W. side	3	37, 39, 40	15	10
6	16, N. of L St.	22	443-445	105	82
7	Mass & 36th	3	51, 52		11
8	Wisc. & R(E side)	4	59, 60	10, 11	12
9	on Key Br.	5	67, 68, 69, 70		15
10	M St., West of Wisc.	6	79, 80, 81	16	17
11	Wisc. & Prospect	6	82, 84	17	17
12	L & 16th, S side	22	438-442	102, 103, 104	82
13					
14	Constit. W. of 23rd	10	126, 127		31
15	K & 16th	24	499, 500, 501	117, 118	88
16	Constit, W. of 17th	12	173, 174, 175	30	42
17					
18	Constit., E. of 17th	12	36, 176	31	42
19	Constit, S of 17th	12	177, 178		42
20	E. St., (W/B) & 19th, E. side	13	185-188	32, 33, 34	45
21	E St., (E/B & 18th St., S. side	13	208, 209	37	49
22	E. St., (E/B) & 17th St., S. side	14	219, 220		53
23	Penn & 18th St., S. side	15	225, 226	38, 40, 41	54
24	Penn & 17th	15	239, 240, 242	64, 66	55

Incoming - Signal Group No. (Voice - Channel No.)	Cabinet No.	Location	Outgoing - Signal Group No. (Voice - Channel No.)	CENTRAL OFFICE
I-1	007	Wisc. Ave. & Woodley Rd.	0-1	WL
	120	Wisc. Ave. & Macomb St.	0-1	
	005	Wisc. Ave. & Newark St.	0-1	
	004	Wisc. Ave. & Porter St.	0-1	
I-2	011	Mass. Ave. & Garfield St.	0-1	WL
I-3	009	Wisc. Ave. & Mass. Ave. & Cathedral Ave.	0-2	GT
I-4	010	Wisc. Ave. & Garfield St.	0-2	
I-5	006	Wisc. Ave. & Edmonds St.	0-2	
	121	Wisc. Ave. & Calvert St.	0-2	
I-6	122	Wisc. Ave. & Hall Place	0-3	
	123	Wisc. Ave. & W Place	0-3	
	002	Wisc. Ave. & Whitehaven Pkway	0-3	
	003	Wisc. Ave. & 34 St.	0-3	
	022	Q St. & 33 St.	0-3	
I-7	012	Wisc. Ave. & R St.	0-4	
	106	Wisc. Ave. & Q St.	0-4	
	105	Wisc. Ave. & P St.	0-4	
	104	Wisc. Ave. & O St.	0-4	
	103	Wisc. Ave. & N St.	0-4	
I-8	017	Wisc. Ave. & M St.	0-5	
I-9	013	M St. & 36 St.	0-5	
	015	M St. & Key Bridge & 35 St.	0-5	
	016	M St. & 34 St.	0-5	

SSMD Document No. 4-2008
UTCS Multiplex Plan
Date: 25 FEB 1972

Tel. Pr. No.	CB No.	Location	Channel No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	7	Wisc. & Woodley	Aϕ																	
	120	Wisc. & Macomb				V89	Aϕ	B24	B62	B121	B122	V90	V104	V105	V106	V107	V128	V144		
	5	Wisc. & Newark		Aϕ																
	4	Wisc. & Porter			Aϕ															
2	11	Mass. & Garfield	V41	Aϕ	V42	V43	V44	V45	V46	V47	V48	V49	V50	V51	V52					
3	9	Wisc. & Mass.	V22	Aϕ	V23	V24	V25	B5	V27	V11	V12	V13	V14	V15	V16	V18	V20			
4	10	Wisc. & Garfield	V28	Aϕ	Bϕ	V30	V32	B6	B7	B15	V33	V34	V35	V37	V39	V40				
5	6	Wisc. & Edmunds	Aϕ																	
	121	Wisc. & Calvert		Aϕ	Bϕ	V7	V8	B19	B20	B21	B22	V9	V10	V17	V19	V21	V26			
6	122	Wisc. & Hall	Aϕ																	
	123	Wisc. & W. Place					V1	B1	B2	B3	B4	Aϕ	V2	V3	V4	V5	V6			–
	2	Wisc. & Whitehaven		Aϕ																
	3	Wisc. & 34			Aϕ															
	22	Q & 33				Aϕ														
7	12	Wisc. & R					V53	B8	B9	B10	B11	Aϕ	V54	V55	V56	V57	V58	V59	V60	
	106	Wisc. & Q	Aϕ	(Aϕ)																
	105*	Wisc. & P	* Electronics for CB 105 located in CB 106																	
	104	Wisc. & O			Aϕ	(Aϕ)														
	103**	Wisc. & N	**Electronics for CB 103 located in CB 104																	
8	17	Wisc. & M	V74	Aϕ	Bϕ	V75	V76	B12	B13	B14	B16	B17	V77	V78	V79	V80	V81	V82	V84	
9	13	M & 36	Electronics for CB 013 located in CB 015																	
	15	M & 35	(Aϕ)	Aϕ	Bϕ			V73	V61	V62	V63	V65	V66	V67	V68	V69	V70			
	16	M & 34				Aϕ	Bϕ													

SSMD Document No. 4-2009
"Channel Frequency Allocation"
Date: 11 Oct. 1972

CENTRAL COMMUNICATION CABINET 505

Row	Column A	B	C	D	E	F	G	H	I	J	K
1	3T 780~ HA 065	3T 420~ HA 066	3T 780~ HA 067	3T 540~ HA 068	3T 660~ HA 069	3T 900~ HA 070	3T 540~ HA 071	3T 900~ HA 072	3T 780~ HA 073	3T 660~ HA 074	3T 660~ HA 075
2	2R 540~ Aϕ 65	2R 780~ Aϕ 66	2R 540~ Aϕ 67	2R 540~ Aϕ 68	2R 1260~ Aϕ 69	2R 540~ Aϕ 70	3T 780~ HA 076	3T 900~ HA 077	S	S	S
3	2R 540~ Aϕ 71	3R 1140~ B73	⊣F	3R 1260~ B68	⊣F	3R 1500~ B81	⊣F	3R 1260~ B79	⊣F	3R 1140~ B78	⊣F
4	2R 540~ Aϕ 72	3R 1020~ B77	⊣F	3R 1380~ B80	⊣F	3R 1260~ B84	⊣F	3R 1380~ B85	⊣F	3R 1020~ B88	⊣F
5	2R 540~ Aϕ 73	3R 1140~ B83	⊣F	3R 1020~ B82	⊣F	3R 1620~ B87	⊣F	3R 1500~ B86	⊣F	3R 1380~ B91	⊣F
6	2R 1020~ Aϕ 74	2R 1020~ Aϕ 75	2R 540~ Aϕ 76	3R 1500~ B92	⊣F	S	S	S	S	S	S
7	Ampl. L14-1 L15-2	2R 540~ Aϕ 77	S	S	S	2R 2100~ V279	2R 1500~ V299	2R 1620~ V300	2R 660~ V272	2R 1980~ V269	2R 1740~ V266
8	S	2R 1500~ V38	2R 2200~ V284	2R 780~ V306	2R 1500~ V309	2R 1980~ V282	2R 1620~ V280	2R 900~ V274	2R 1860~ V267	2R 1740~ V302	2R 660~ V320
9	Ampl. L26-1 L27-2	2R 780~ V321	2R 1980~ V97	2R 1860~ V312	2R 1860~ V98	2R 900~ V307	2R 1380~ V308	2R 420~ V285	2R 2100~ V283	2R 1620~ V317	2R 420~ V319
10	S	2R 420~ V221	2R 660~ V222	2R 1380~ V315	2R 660~ V313	2R 1860~ V343	2R 1500~ V316	2R 420~ V295	2R 900~ V323	2R 780~ V224	2R 900~ V327
11	Ampl. L31-1 L32-2	2R 780~ V326	2R 1380~ V328	2R 1620~ V330	2R 1500~ V148	2R 900~ V237	2R 1500~ V329	2R 420~ V235	2R 1740~ V311	2R 1620~ V310	2R 1980~ V344
12	S	2R 1860~ V332	2R 1260~ V314	2R 1620~ V341	2R 1740~ V342	2R 1500~ V340	2R 1380~ V339	2R 1740~ V350	2R 900~ V348	2R 420~ V334	2R 1980~ V352

S - Spare
⊣F - Filter for adjacent 3-frequency bus receiver

DETAILED COMPUTER SYSTEM EVALUATION WORK SHEET

1. PERFORMANCE

1.1 Throughput 1

1.1.1 Processing

- Is instruction set suitable
- Operation times; ADD
  - MPY
  - Logical instruction
  - I/O
- Registers (general, index, etc.)
- Real-time supervieor - Worker Modes/Multiprocessing
- Interrupt Capabilities (external/internal)
- Addressing (direct, indirect, relative)

1.1.2 Processing Capacity _____ ips with ADD/MPY ratio = _____

1.1.3 Processing Margin $\left(\frac{\text{Processing Capacity - (total basic + Growth Reqmt.)}}{\text{Proceesing Capacity}} \times 100\right)$

1.1.4 Input/Output

- I/O channels (DMA, dedicated, burst)
- Multiplexer channels
- Dependency on ACU (hardware integration)
- Transfer rate/burden on memory and processor
- Interrupt detection and handling
- Software requirements (complexity, chaining)

Note 1: If practical and cost effectiv ., throughput should be evaluated using a bench mark test program designed specifically for the problem to be solved.

- Communications capabilities
  - Number lines/types/rates
  - Adaptability
- Interface (noise, compatibility, cable lengths)

1.1.5 Growth Featuree/Flexibility

- Ease of installation of options/availability/modularity
- Obsolescence factor
- Compatibility with other vendor computers
- Options
  - Arithmetic
  - Power failure/restart/power recovery
  - Bootstrap
  - Failure detection
  - Microprogramming

1.1.6 Degraded Operation Capability

1.2 Precision

- Single arithmetic bits
- Double arithmetic bits

1.3 Memory

- Capacity - basic
  - additional units

SAMPLE

- Cycle time
- Organization (word/byte/bit)
- Features - electrically alterable
  - DRO
  - NDRO
  - ROM
  - Memory protect
- Type (core, thin film, plated wire, etc.)
- Capacity Margin - on line % Available (basic + growth reqmt.)
- Capacity Margin - off line % Available

1.4 Peripherals

1.4.1 Required Peripherals Included (Vendor/Others)

- Storage devices (core, drum, disc, mag tapes)
- A/D and D/A converters
- Displays (plotters, CRT)
- Printers/readers/punches
- Consoles
- Communication devices

1.4.2.6 Capability

- Capacity
- Speed

- Precision
  - Error detection/correction
- Interface

1.4.3 Growth Features/Flexibility

- Ease of installation of option/availability/modularity
- Obsolescence factor
- Compatibility with other vendor computers
- Options
- Degraded operation capability

1.4.4 Additional Peripherals Available

1.5 Environmental Requirements (Processor and Peripherals)

- Cooling requirements
- Temperature/Humidity
- Power requirements
- Cleanliness requirements
- Shock requirements
- Radio Frequency Interference (Emission and Susceptibility)

1.6 Physical Characteristics

- Physical dimensions
- Weight

SAMPLE

- Hardware packaging
  - Modular
  - State of art
  - Appearance
- Noise - effect on surrounding area
- Operator human factors
  - Panel lighting, intensity
  - Controls, pushbuttons, etc.
- Installations requirements
  - site pre-installation requirements
  - cabling
- Restricted materials (are any used?)

1.7 Programming Languages and Subroutines Available

- Executive/supervisor systems
  - Real-time
  - Background/foreground
  - Batch
  - Time-shared
  - Multiprogramming
  - Multiprocessing
  - I/O control
- Job control languages
- Assembly languages
- Procedure/problem oriented languages (FORTRAN, COBOL)

- Simulation languages (GPSS, SIMSCRIPT)
- Report generation packages (RPG)
- Application packages (Business, EDP)
- Programming aids (library, debugging, utility)
- Data base management systems
  - File structure
  - User capability

1.7.2 Status of Software Packages

- Availability/risk of meeting dates
  - Customizing for our application
- Future support/enhancements
  - User's groups
- Documentation status
- Training available
- Experience of other users

1.7.3 Implementation of Programming/Software

- Availability/familiarity in-house
- Other sources available
  - Job shop/software house/vendor
  - Purchase existing programs

SAMPLE

1.7.4 Other Considerations

- Efficiency of software packages
- System requirements to utilize software (loading, etc.)
  - Compatibility with in-house and production systems
  - Peripherals/core memory required
  - Availability on other systems
- Standard vs. special purpose/customizing
- Compatibility with other vendor systems and industry

1.8 Subroutines (Included in Above)

1.9 Instruction Repertoire Adequacy

(List instructions required for which there is either no instruction in repertoire or for which more than one instruction must be used)

2. OPERATIONAL SUPPORT

2.1 Reliability/Availability

- Mean Time Between Failures (MTBF)
  - Major units
  - Total system
- Mean Time to Repair (MTTR)
- Malfunction detection and monitoring
  - Parity, checksums, diagnostics
  - Alarms, heat, power, etc.
  - Self-protect features
- Physical construction/accessibility for maintenance and repair

- Preventive maintenance requirements
- Level of technician/training required
- Factors affecting MTBF and MTTR
  - Redundancy of elements
  - Modularity
  - Experience of others
  - Diagnostic aids
  - Built in test equipment/special equipment needed
  - Documentation
  - Degraded operation capability/alternatives

2.2 Operational and Maintenance Documentation

(List material available)

- Configuration control

2.3 Training Courses Available

- Hardware
- Software
- Operations
- Facilities (locations)

2.4 Availability of On-Site Service

- Manufacturer service organization exists
- Service center locations
- Customer already utilizes service

SAMPLE

- Manufacturers service efficiency
- Special arrangements required
- Can SSMD provide service?

2.5 Availability of Repair Service

- Manufacturer logistic system exists
- Logistics system efficiency/serivce area location
- Repair center locations
- Representative turn-around times
- Special arrangements required
- Service charge accounting

2.6 Availability of Spare Parts

- In Sperry stock
- In customer stock
- Readily available outside manufacturer
- Readily available from manufacturer
- Warehouse locations
- Special Arrangements required

3. COST AND SCHEDULE

3.1 Acquisition Cost

- Basic system (Note: Technical characteristics should be given in terms of the basic system for each computer)
- Additional 4K memory, 8K, 16K Total Cost and cost/unit (work/byte/bit)

- Memory parity
- Expansion chassis
- Memory protect
- Power failure protect
- Multiply and divide option
- Real-time clock
- Priority interrupts (specify levels)
- Direct memory access
- Buffered I/O controller
- Buffered interface controller
- Additional parallel channels (1, 2, 4, 16)
- Additional serial channels (1, 2, 4, 16)
- ASR-33 teletype
- ASR-35 teletype
- I/O console
- Paper tape reader/punch
- Magnetic tape unit (1, 2, 4, drives)
- Disc system (1, 2 disc drives)
- Disc file system (1, 2 stacks)
- High speed printer
- Card reader
- Card punch

SAMPLE

- Plotter
- Magnetic drum (drums)
- Computer driven display
- Communications terminal (per channel)
- A/D converter (per channel)
- Support software package (state complement)
- Procedures package (state complement)
- Repackaging
- Installation
- Special tool/test equipment (itemize)
- Environmental control
- Spares
- Documentation

Note: If a particular item does not apply to a program indicate "N/A" in appropriate spaces. If a particular item is included in the basic system enter "B" in appropriate spaces. Costs and schedules shall be determined where applicable in quantities of "1", "X" and "Y". Items particular to a program not included in the above list shall be added to individual rating forms.

3.2 Schedule

- 1st Article
  - Factory test
  - Installed and checked out
- Production availability

3.3 Maintenance Costs

- Fixed price contract
- On-call
- Spares replacement

3.4 Discounts and Warranty

- Price guarantees
- Discount
- Warranty practices

4. OTHER FACTORS

4.1 Sperry/Manufacturer Relationship

- Possible in-house conflict
- Expected cooperation
- Customer familiarity
- In-house experience
- Competition risk
- Manufacturing facilities

4.2 Customer/Manufacturer Relationship

- Product familiarity
- Problems experienced (reliability/service, software, programming, etc.)
- Customer opinions

SAMPLE

4.3 Model Commonality

- Software commonality
- Hardware commonality (at assembly, subassembly and module levels)
- Available procedure repertoire (which may be of interest to customer)
- Follow-up capability
- Quantity sold
- Quantity on order
- Quantity of expected orders

4.4 Growth Capability

List features and/or capability now available or under development

4.5 Customer Furnished Equipment Availability

- Items (and quantities)
- Manufacturer
- Schedule

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SAMPLE

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Section 4

A. Urban Traffic Control and Bus Priority Systems - Software Manual, SSMD Pub. No. GF-16-1003, November 1972.

Section 5

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B. Urban Traffic Control and Bus Priority System - Operator's Manual, SSMD Pub. No. GF-15-1003, September 1972.

C. Urban Traffic Control and Bus Priority System - Maintenance Manual, SSMD Pub. No. GF-14-1001, November 1972.

Note: PB-designated references are available from:

National Technical Information Services
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Springfield, Virginia, 22151

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